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SYNTHESIS AND CHARACTERIZATION OF A MANGANESETARTRATE COORDINATION COMPLEX: UV-VIS SPECTROSCOPIC AND THERMAL STUDIES

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Abstract

A Manganesetartrate coordination complex was synthesized and characterized using ultraviolet-visible (UV-Vis) spectroscopy and thermogravimetric analysis (TGA/DTA). The optical properties of the complex were investigated in the wavelength range of 200-800 nm using a Cary 5000 UV-Vis-NIR spectrophotometer. The UV-Vis spectrum revealed a strong absorption band at 239.896 nm, which was attributed to ligand-centered electronic transitions associated with the tartrate moiety. The thermal behavior of the synthesized complex was evaluated using a DTG-60 thermal analyzer under an argon atmosphere at a heating rate of 10 °C min^{-1}. Thermogravimetric analysis demonstrated a multistep decomposition process consisting of four major stages. The first stage corresponded to the removal of physically adsorbed and coordinated water molecules, while the subsequent stages were associated with the progressive decomposition of the tartrate ligand and destruction of the coordination framework. The final decomposition product was identified as thermally stable manganese oxide residue. The obtained results indicate that the synthesized Manganesetartrate complex possesses characteristic ligand-based optical properties and moderate thermal stability. These findings contribute to a better understanding of the physicochemical behavior of manganese tartrate coordination compounds and their potential applications in coordination chemistry and materials science.

Keywords: manganese complex, potassium tartrate, coordination compound, UV-Vis spectroscopy, thermogravimetric analysis, thermal stability, manganese oxide

Introduction

Coordination chemistry remains one of the most rapidly developing fields of inorganic chemistry due to the unique structural, electronic, catalytic, and physicochemical properties exhibited by metal-ligand systems. Coordination compounds have attracted significant attention because of their wide applications in catalysis, electrochemistry, pharmaceuticals, environmental remediation, materials science, and nanotechnology. The properties of coordination compounds are strongly influenced by the nature of the central metal ion, the type of ligand, and the coordination environment formed during complexation. Among transition metals, manganese is of particular

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interest because of its abundance, relatively low toxicity, environmental compatibility, and ability to exist in multiple oxidation states ranging from +2 to +7. This versatility enables manganese to form a wide variety of coordination compounds with diverse geometries and physicochemical characteristics. Manganese-containing complexes have been investigated for their catalytic activity, redox behavior, magnetic properties, and potential applications in advanced functional materials. In particular, Mn(II)-based complexes have attracted considerable interest owing to their stability and ability to coordinate with oxygen-donor ligands. Tartrate ligands represent an important class of naturally occurring organic compounds capable of forming stable coordination complexes with various metal ions. The tartrate ion contains two hydroxyl groups and two carboxylate groups, which provide multiple coordination sites for metal binding. As a result, tartrate ligands can act as mono-, bi-, or multidentate ligands and can generate diverse coordination architectures. Metal-tartrate complexes have been reported to exhibit interesting structural, optical, thermal, and electrochemical properties, making them attractive for both fundamental and applied research.

The interaction between manganese ions and tartrate ligands leads to the formation of coordination compounds in which the ligand environment significantly influences the electronic structure and thermal behavior of the resulting complex. Investigation of such interactions is important for understanding the relationship between molecular structure and physicochemical properties. Furthermore, manganese-tartrate complexes may serve as potential precursors for the preparation of manganese oxide materials, which are widely utilized in catalysis, batteries, sensors, and environmental technologies. The characterization of newly synthesized coordination compounds requires the application of reliable analytical techniques capable of providing information about their composition, structure, and stability. Among these techniques, ultraviolet-visible (UV-Vis) spectroscopy is extensively used for studying electronic transitions and metal-ligand interactions in coordination systems. UV-Vis spectroscopy provides valuable information regarding the electronic structure of complexes and allows the identification of ligand-centered, metal-centered, and charge-transfer transitions. In manganese(II) complexes, electronic spectra are generally dominated by ligand-based transitions because d-d transitions are weak due to spin-forbidden selection rules. Thermal analysis techniques, including thermogravimetric analysis (TGA) and differential thermal analysis (DTA), are widely employed to evaluate the thermal stability and decomposition pathways of coordination compounds. These methods provide detailed information regarding dehydration processes, ligand decomposition, phase transformations, and the formation of final decomposition products. The thermal behavior of metal-organic complexes is particularly important because it determines their stability during storage, processing, and potential industrial applications. In addition, thermal decomposition studies contribute to understanding the bonding nature between metal ions and coordinated ligands.

Materials and Methods

UV-Visible Spectroscopy

The optical properties of the Manganesetartrate complex were investigated using a Cary 5000 (Agilent Technologies) UV-Vis-NIR spectrophotometer. The measurements were performed in the wavelength range of 200-800 nm using a quartz cuvette with an optical path length of 1 cm. The absorbance spectrum was recorded at room temperature.

Thermal Analysis

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Thermal characterization of the synthesized complex was carried out using a DTG-60 (SHIMADZU) thermal analyzer. The analysis was performed in the temperature range of 25-800 °C under an argon atmosphere with a gas flow rate of 100 mL min^{-1}. The heating rate was maintained at 10 °C min^{-1}, and the initial sample mass was 5.177 mg.

Results and Discussion

UV-Visible Spectroscopic Analysis

The UV-Visible absorption spectrum of the Manganesetartrate complex was recorded in the wavelength range of 200-800 nm and is shown in Figure 1. UV-Vis spectroscopy is one of the most important analytical techniques for investigating the electronic structure of coordination compounds, as it provides valuable information about ligand-metal interactions, charge transfer processes, and electronic transitions occurring within the complex molecule.

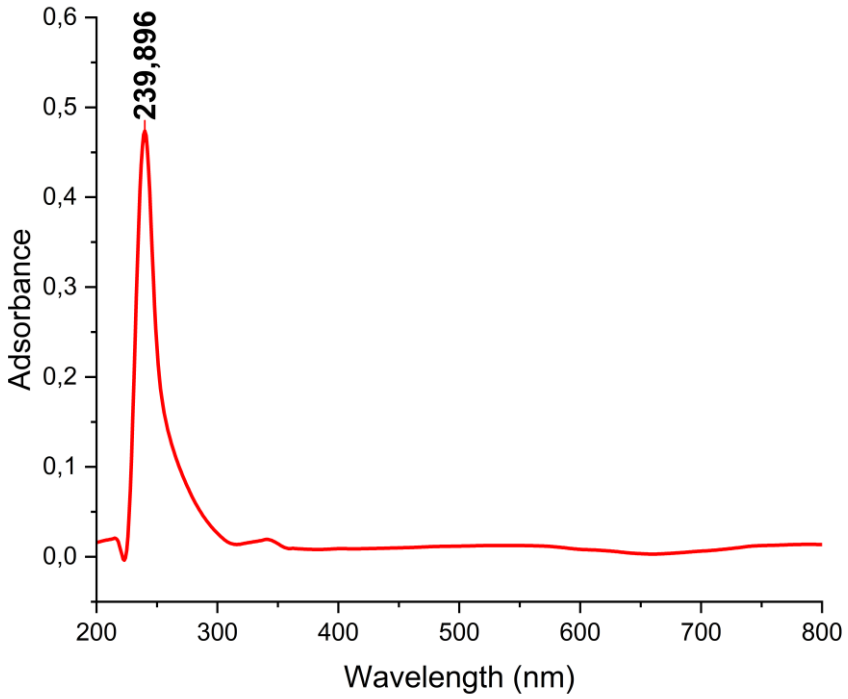

Figure 1. UV-Visible absorption spectrum of the Manganesetartrate complex showing the characteristic absorption maximum at 239.896 nm attributed to ligand-centered electronic transitions.

The obtained spectrum exhibits a strong and well-defined absorption band at λmax =239.896 nm, indicating the presence of highly energetic electronic transitions in the ultraviolet region. This absorption peak is mainly attributed to ligand-centered n→π* transitions associated with the oxygen-containing functional groups of the tartrate ligand. The tartrate ion contains both hydroxyl (-OH) and carboxylate ($-COO^-$) groups, which possess non-bonding electron pairs capable of participating in electronic excitation processes. Upon absorption of ultraviolet radiation, electrons from non-bonding orbitals are promoted to antibonding π* orbitals, resulting in the observed absorption band.

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The relatively high intensity of the absorption peak suggests efficient electronic interaction between the ligand and the metal center. Coordination of the tartrate ligand to Mn(II) ions can alter the electron density distribution within the ligand framework, leading to slight shifts in absorption wavelengths compared with those of free tartaric acid. Such spectral changes are commonly regarded as evidence of complex formation and successful coordination between metal ions and organic ligands.

In addition to confirming coordination, the absorption band observed near 240 nm reflects the stability of the ligand environment around the manganese center. The presence of a single dominant absorption peak indicates that the electronic structure of the complex is primarily governed by ligand-based transitions rather than extensive charge-transfer processes. Similar absorption behavior has been reported for manganese complexes containing oxygen donor ligands, where the ultraviolet region is dominated by intraligand electronic transitions.

A notable feature of the spectrum is the absence of significant absorption bands in the visible region (400-800 nm). This observation is consistent with the electronic configuration of Mn(II) ($3d^5$) ions. In octahedral or distorted octahedral coordination environments, d-d electronic transitions of Mn(II) are both spin-forbidden and Laporte-forbidden, resulting in very weak absorption intensities. Consequently, these transitions are often difficult to detect in conventional UV-Vis spectra and do not contribute significantly to the optical response of the complex.

The low absorbance observed above 300 nm indicates that the synthesized complex possesses relatively high transparency in the visible region. This characteristic suggests that the compound does not contain strongly conjugated chromophoric systems and further supports the conclusion that the observed absorption arises predominantly from localized electronic transitions within the tartrate ligand. The spectral profile therefore reflects the electronic nature of the coordinated organic framework rather than metal-centered transitions.

Furthermore, the absorption maximum at 239.896 nm can be considered an important spectroscopic fingerprint of the Manganesetartrate complex. The position and intensity of this band provide evidence for the successful incorporation of manganese ions into the coordination structure and can be used as a reference for future comparative studies involving related manganese carboxylate complexes.

Thermal Analysis

The thermal stability and decomposition behavior of the Manganesetartrate complex were studied using simultaneous thermogravimetric analysis (TGA) and differential thermal analysis (DTA). The measurements were carried out in the temperature range of 25-800 °C under an argon atmosphere. The obtained thermogram shows that the complex does not decompose in a single step, but undergoes a multistage thermal degradation process, which is typical for metal-organic coordination compounds containing hydrated molecules and organic ligands.

According to the TGA curve, the first mass-loss stage occurs in the temperature range of 31.65-89.83 °C, with a mass loss of 4.93%, corresponding to 0.255 mg. This stage is mainly attributed to the removal of physically adsorbed water and crystal hydration water molecules from the complex structure. The presence of an endothermic peak at 86.79 °C in the DTA curve supports this assignment, since dehydration processes usually require heat absorption. This result indicates that water molecules are weakly bound in the crystal lattice and are released at relatively low temperatures.

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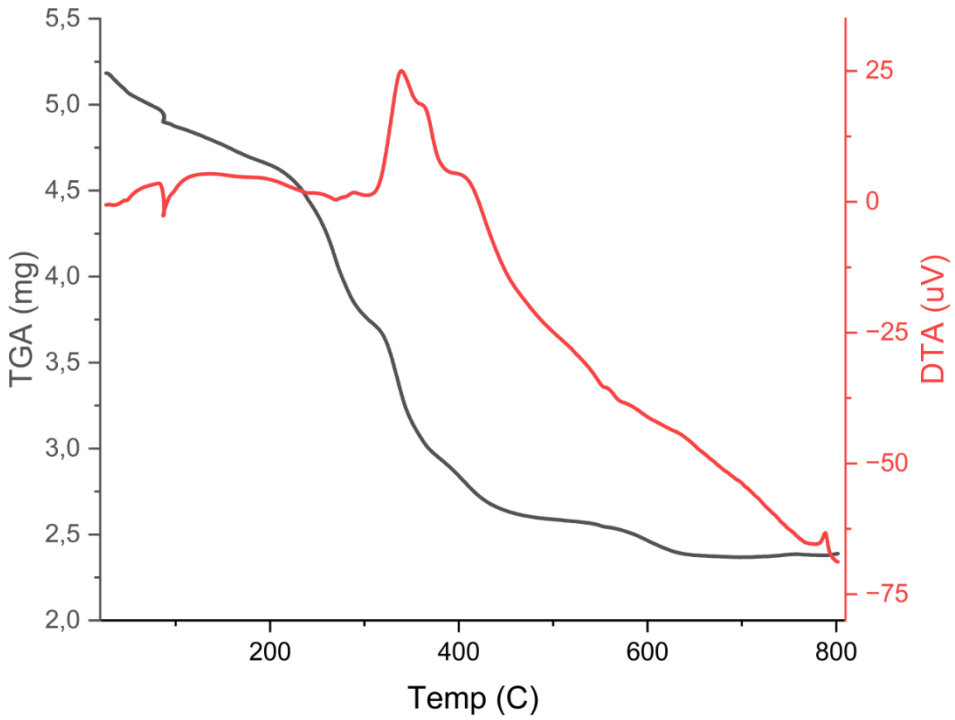

Figure 2. TGA and DTA analysis of the complex compound

The second thermal decomposition stage is observed between 89.83 and 300.17 °C, where the sample loses 22.25% of its initial mass, equal to 1.152 mg. This is the most intensive mass-loss stage in the low-temperature region and can be associated with the initial decomposition of the tartrate ligand. During this process, partial cleavage of organic fragments, removal of volatile products, and weakening of metal-ligand interactions may occur. The endothermic effect near 268.88 °C confirms that this stage involves energy-consuming decomposition processes related to the organic ligand framework.

The third stage takes place in the temperature interval of 300.17-442.24 °C and results in an additional mass loss of 21.58%, corresponding to 1.117 mg. This stage is associated with deeper degradation of the remaining organic components of the complex. At this temperature range, the tartrate framework is further destroyed, coordination bonds are broken, and carbon-containing fragments are decomposed. The DTA curve shows a distinct exothermic peak at 342.58 °C, which indicates that oxidation, structural rearrangement, or combustion-like decomposition of residual organic fragments occurs during this stage. The sharp nature of this thermal effect suggests that the decomposition process is relatively intensive.

The fourth decomposition stage occurs between 442.24 and 628.94 °C, with a relatively small mass loss of 4.69%, equal to 0.243 mg. This stage can be attributed to the final destruction of residual organic fragments and the gradual transformation of the complex into a stable inorganic phase. The endothermic peak observed at 571.98 °C confirms the occurrence of structural transformation in this temperature region. After this stage, the organic part of the complex is almost completely removed, and the remaining mass corresponds mainly to inorganic manganese-containing products.

Above approximately 630 °C, the TGA curve becomes nearly horizontal, indicating that no significant further mass loss occurs up to 800 °C. This behavior confirms the formation of a

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thermally stable inorganic residue. The final residue accounts for approximately 46% of the initial sample mass and may be assigned to manganese oxide, mainly MnO, formed after complete decomposition of the Manganesetartrate complex.

Thus, the thermal analysis demonstrates that the synthesized complex is relatively stable up to about 90 °C, after which dehydration and ligand decomposition begin. The overall thermal decomposition proceeds through four clearly distinguishable stages: dehydration, initial ligand degradation, intensive destruction of the organic framework, and formation of a stable inorganic oxide residue. These results confirm that the Manganesetartrate complex possesses moderate thermal stability and a well-defined stepwise decomposition mechanism, which is characteristic of coordination compounds containing carboxylate-based organic ligands. Table 1. Thermal decomposition stages of the Manganesetartrate complex

Table 1.

TGA Analysis Results of the Mn–Potassium Tartrate-Based Complex Compound

Stage	Temperature Range (°C)	Mass Loss (%)	Mass Loss (mg)	Process
Stage 1	31.65-89.83	4.93	0.255	Evaporation of crystal hydration water
Stage 2	89.83-300.17	22.25	1.152	Initial decomposition of tartaric acid
Stage 3	300.17-442.24	21.58	1.117	Decomposition of organic components
Stage 4	442.24-628.94	4.69	0.243	Complete destruction

Conclusion

A Manganesetartrate coordination complex was successfully characterized using UV-Visible spectroscopy and thermal analysis. The UV-Vis spectrum exhibited a strong absorption band at 239.896 nm, indicating ligand-centered electronic transitions associated with the tartrate ligand. Thermal analysis revealed a four-stage decomposition mechanism involving dehydration, ligand degradation, and gradual destruction of the coordination framework. The final residue corresponded to thermally stable manganese oxide, accounting for approximately 46% of the initial sample mass. The obtained results confirm the successful formation of the Manganesetartrate complex and provide valuable information regarding its optical properties and thermal stability. Such characteristics suggest potential applications of this material in coordination chemistry, advanced materials research, and functional inorganic systems.

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