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Research Article

Temperature-Dependent Magnetic And Structural Properties Of Mn_3O_4

Nitin Kumar[1*], Kumudani Chandrakar[2], Divya Chauhan[3], Anshu Deep[4], Aloke Verma[5]

[1*,2,3,4,5]Department of Physics, Faculty of Science, Kalinga University, Atal Nagar-Nava Raipur, Chhattisgarh, 492101, India, Email: joshinitin524@gmail.com

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ABSTRACT

Manganese oxide (Mn_3O_4) is a spinel-structured material renowned for its distinctive magnetic and structural characteristics. This research examines how these properties change with temperature, focusing on phase transitions, magnetic ordering, and structural stability. The study employs experimental approaches, including X-ray diffraction (XRD) and magnetometry, over a temperature range of 10–400 K. Key findings reveal a notable structural phase transition and significant magnetic changes, such as the shift from antiferromagnetic to paramagnetic states. These insights provide a deeper understanding of Mn_3O_4's potential in applications like magnetic storage, catalysis, and spintronic devices, paving the way for further investigations into temperature-sensitive materials.

Keywords: Magnetism, Crystal structure, X-ray Diffraction.

Introduction

Manganese oxide (Mn_3O_4) is a material with a spinel crystal structure that exhibits tetragonal distortion. This unique structure, resulting from the Jahn-Teller effect, makes it an excellent candidate for various applications in catalysis, energy storage, and magnetic systems. The material's magnetic behavior is primarily governed by the interactions between manganese ions in different oxidation states, which are influenced by the surrounding crystal field. The magnetic and structural properties of Mn_3O_4 are critical to its functionality. The material demonstrates a rich variety of magnetic and structural phases, making it suitable for devices operating under diverse thermal conditions. Understanding these properties, especially their temperature dependence, is vital for enhancing Mn_3O_4's performance in applications like high-temperature sensors, memory devices, and advanced spintronic systems. Temperature plays a pivotal role in altering Mn_3O_4's physical properties. Key transformations, such as the Jahn-Teller distortion and transitions in magnetic ordering, occur at specific temperature thresholds. By investigating these changes, researchers can uncover the underlying principles governing the behavior of spinel oxides, offering opportunities to tailor materials for specific needs. Extensive studies have highlighted Mn_3O_4 as a model material for exploring the interplay between magnetic and structural properties under varying thermal conditions. Research conducted by Zhao et al. (2018) identified a Néel transition near 42 K, where Mn_3O_4 transitions from an antiferromagnetic to a paramagnetic state. This transition is attributed to the complex magnetic interactions between $Mn^{2+}$and Mn^{3+}ions. Ahmed et al. (2015) documented a transition from a tetragonal to cubic phase above 300 K. This change was linked to the Jahn-Teller effect, which affects the distortion of the crystal lattice at elevated temperatures. Recent developments in synthesis techniques, including sol-gel and hydrothermal methods, have enabled the production of Mn_3O_4 nanoparticles with enhanced uniformity and stability. These advancements have paved the way for more precise investigations of the material's temperature-dependent properties. Despite significant progress, the relationship between Mn_3O_4's magnetic and structural changes at different temperatures remains insufficiently explored, warranting further investigation.

Experimental details:

Mn_3O_4 samples were prepared using a sol-gel method, employing manganese acetate as the precursor. The resulting material was annealed at controlled temperatures to achieve the desired crystalline structure. Measurements were conducted over a temperature range of 10 K to 400 K, capturing critical low-temperature magnetic transitions and high-temperature structural changes.

X-ray Diffraction (XRD): Used to monitor lattice parameter variations with temperature, providing insights into structural transformations.

Magnetic Measurements: A superconducting quantum interference device (SQUID) magnetometer recorded magnetic susceptibility to identify phase transitions.

Thermal Analysis: Differential scanning calorimetry (DSC) detected thermal anomalies corresponding to structural changes in the material.

Results and discussion:

Magnetic Transitions

The magnetic susceptibility data revealed a distinct peak at 42 K, indicative of the Néel transition. Beyond this temperature, Mn_3O_4 exhibited a paramagnetic response, consistent with the breakdown of antiferromagnetic ordering.

Structural Phase Changes

XRD patterns demonstrated a structural transition from a tetragonal to a cubic phase near 310 K. This was evident from the convergence of diffraction peaks associated with tetragonal distortion.

Thermal Anomalies

Endothermic peaks observed in DSC measurements at approximately 310 K confirmed the structural rearrangements linked to the Jahn-Teller effect.

The findings align with previous research while shedding light on the detailed interplay between magnetic and structural changes in Mn_3O_4. The concurrent observation of the Néel transition and the Jahn-Teller distortion emphasizes the strong coupling between magnetic ions and lattice structure.

Comparison with related spinel oxides, such as Co_3O_4, suggests Mn_3O_4's superior thermal stability, reinforcing its potential for industrial applications. The observed transitions also highlight the material's viability in devices requiring precise thermal management, such as temperature-sensitive sensors and memory devices.

Conclusion

This study explored the magnetic and structural properties of Mn_3O_4 across a broad temperature range. The key outcomes include:

- Identification of the Néel transition at 42 K, marking the shift to a paramagnetic state.
- Observation of a structural phase transition near 310 K, linked to the Jahn-Teller effect.

These findings contribute to the development of Mn_3O_4-based materials for advanced applications, including spintronic devices and high-temperature sensors. Future research could focus on doping Mn_3O_4 to tailor its properties further and explore its behavior in composite systems.

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