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Magnetic Ordering Phase Transitions of $Gd_2Sn_2O_7$

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Abstract

Pyrochlores with magnetic rare earth ions are a topic of interest due to unusual results brought about by their high degree of geometrical frustration. The lattice structure prevents the magnetic spin interactions from finding a single minimum energy state, which leads to a nonzero residual entropy[1]. By analyzing the heat capacity at low temperatures, the type of magnetic interaction can be determined and the temperatures at which long-range magnetic ordering and magnetic field induced splitting of energy states occur.

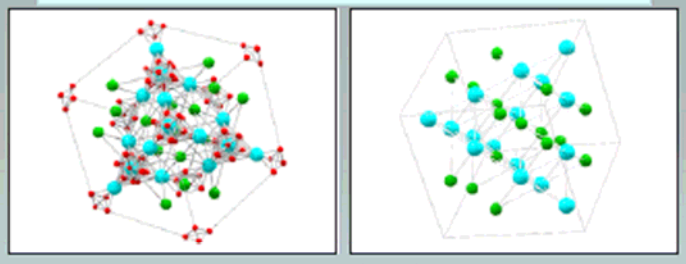

Figure 1: (a) $Gd_2Sn_2O_7$ unit cell, (b) unit cell with oxygens removed

Experimental Details

The heat capacity measurements were taken at UNLV using the Quantum Design PPMS (Physical Property Measurement System) equipped with a He-3 system attachment and puck(Fig.1). The system is capable of achieving ~0.36K by means of helium-3 and a pump to expel heat from the system. Addenda measurements were first taken from 30K-0.36K at different field strengths, ranging from 0-9 T. The experiment was then repeated with a 1.52mg sample, with the addenda serving as backgrounds.

The graph of the total heat capacity of the sample is a superposition of several different contributing factors. The heat capacity measurements contain lattice contributions, Schottky anomalies, and long-range magnetic ordering. By using the Debye model for low temperatures, a T^3 curve can be used to approximate the lattice contribution. After removing the lattice contribution, the short-range ordering term can be fitted to Schottky peaks using a Mathcad program. With the removal of the two contributing factors, the long-range ordering peak is found by using a Lorentzian function.

Figure 1: PPMS(left), He-3 puck accessory kit(right)

CONCLUSIONS

The inverse relationship between temperature and magnetic field in the experiment shows that $Gd_2Sn_2O_7$ orders antiferromagnetically, in agreement with previous works[2]. There also seems to be evidence of magnetic induced splitting of low-level energy states, shown by Schottky peaks. Though there were temperature limitations in our experimental equipment, it was possible to extrapolate data beyond of our measuring capabilities. As a result, long-range ordering should not be observed at any temperature for field strengths greater than our theoretical value of 5.779T.

Results

The graph of the total heat capacity of the sample took on the unique curve shown(Fig.2), verifying multiple factors contributing to the heat capacity. Beyond 17K, the magnetic interactions appear to vanish, denoting the position for the Debye curve to be fitted to. Multiple round peaks suggest that there are more than one Schottky peak, for different excited magnetic states. The shift of the peak center with field suggests an increase in the characteristic temperature of the splitting between the states.

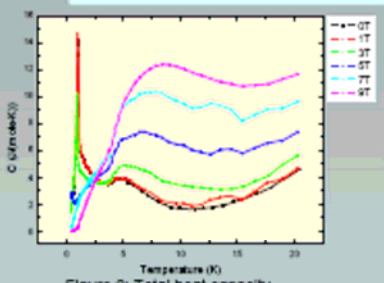

Figure 2: Total heat capacity

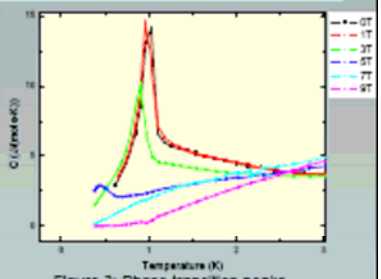

Figure 3: Phase transition peaks

The results show that the ordering peak shifts to lower temperatures with increasingly strong applied fields(Fig.3). The separation between the peaks also increases with increasing field strength. With no applied field, the temperature at which the magnetic ordering phase transition occurs is just under 1K. Similarly, the temperatures at which the phase transitions occur at fields of 1, 3, and 5T can be seen in the graph. For fields of strength 7T and 9T, the temperatures where the transitions occur can no longer be measured by the PPMS. The graph of the phase transition peaks reveals that heat capacity decreases with increasing field, contrasting that of the Schottky peaks. An insufficient amount of data points causes the 0T peak to not be well resolved.

A plot of temperature vs. applied magnetic field (Fig. 4) shows the phase boundary between ordered and disordered magnetic states. The phase boundary curve is used to extrapolate to determine the critical field at which long-range ordering cannot occur even at absolute zero. The black points are the measured data points. The red point is the extrapolated point. The data indicates a critical field strength of approximately 5.779T. This result reveals that even if the PPMS were capable of going to lower temperatures, even as low as absolute zero, phase transitions for 7T and 9T would not occur, making the 7T and 9T curves sufficient for our experiment.

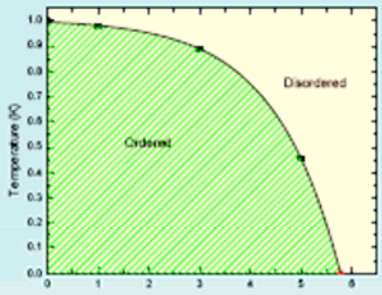

Figure 4: Phase diagram

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[2] A.S. Wills *et.al.*, J. Phys.: Condens. Matter 18 (2006)

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