Magnetic properties of $Ho_2Ru_2O_7$ and $Dy_2Ru_2O_7$ pyrochlores

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Abstract

Magnetic measurements were carried out on $Ho_2Ru_2O_7$ and $Dy_2Ru_2O_7$ pyrochlores to study the possibility of spin ice type magnetism in these systems. Curie Weiss law fits to inverse susceptibility data in the temperature range 200K-350K gave p_{eff}=9.60, θ=-4 K for the Ho and p_{eff}=10.54, θ=-8.4 K for the Dy system. The saturation magnetization at 2 K was only half the value expected for the ground state configurations of the rare earth ions. The effective near neighbour interaction was estimated to have small positive values for both the systems. This suggests that these pyrochlore systems have a magnetic behavior similar to the other spin ice systems despite the presence of the small moment bearing 4d Ru ions which themselves order into antiferromagnetic state at an elevated temperature of about 100 K.

Key words: Spin Ice; Pyrochlore; $Ho_2Ru_2O_7$; $Dy_2Ru_2O_7$

1. Introduction

The magnetic disorder in geometrically frustrated pyrochlore oxides has an analogy to the disorder of protons in water ice and they are referred to as spin ice materials [1]. Three pyrochlore systems have been reported to confirm to the properties expected for spin ice behavior: $Ho_2Ti_2O_7$, $Dy_2Ti_2O_7$, and $Ho_2Sn_2O_7$. There is only one magnetic moment bearing ion (the rare earth ion) in all these compounds and the geometrical frustration arises due to a the corner linked tetahedral network of these ions. It may therfore be of interest to look at the magnetic behavior of other pyrochlore systems based on Ho and Dy: $Ho_2Ru_2O_7$ and $Dy_2Ru_2O_7$. However Ru also has a small magneic moment and it was thought appropriate to look for the influence this might have on the magnetism of the tetrahedral network of the rae earth ions. A complete series of Ru and rare earth (and Y) based pyrochlore compounds was first studied by Ito et al.[2], who observed an antiferromagnetic transition in the tempearture range 75 K - 160K depending on the ionic size of the rare earth ion. In this study we measured the magnetic susceptibility and field dependence of magnetization down to 2 K and observed that these systems also have characteristics of spin ice behavior similar to the three other known spin ice compounds.

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2. Results and Discussion

Figure 1 shows the temperture dependence of susceptibility for the $Dy_2Ru_2O_7$ pyrochlore system measured in a field of 100 Oe in the temperature range 2K-350K. A similar behavior was observed for the Ho based pyrochlore oxide [3]. From Curie Weiss fits to data the effective magnetic moment was determined to be 9.60(1) μ_B and 10.54(1) μ_B per ion for the Ho and Dy pyrochlore systems respectively. The Curie Weiss θ were -4.0(5) K and -8.4(6) K respectively for the Ho and Dy based pyrochlores. Corresponding to the transition temperatures observed by Ito et al. we also observed a small irreversibility effect between the field cooled and zero field cooled susceptibilities at 95 K for

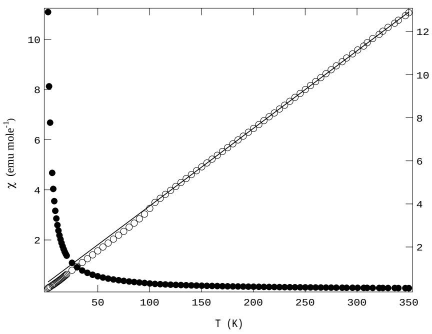

Fig. 1. Susceptibility (χ) and its inverse as a function of temperature after correction for demagnetization field. The solid line through inverse susceptibility data is Curie Weiss fit to data in the temperature interval 200K - 350K

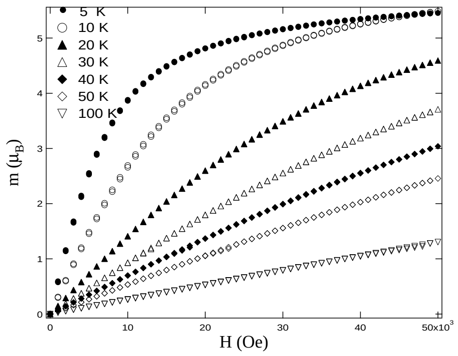

Fig. 2. Isothermal magnetization per magnetic ion (m) versus applied field at different temperatures for $Ho_2Ru_2O_7$ pyrochlore

the $Ho_2Ru_2O_7$ pyrochlore. Figure 2 shows the magnetization data for the $Ho_2Ru_2O_7$ pyrochlore. The saturation of magnetic moment per magnetic ion is taking place at a value which is almost one half of the moment value $10\mu_B$ expected for the 5 I_8 ground state configuration of Ho3+ ion. For $Dy_2Ru_2O_7$ system the saturation moment (figure 3) is once again seen to saturate to about half the expected moment for the ground stae configuration of the Dy3+ ion. This behavior has been understood to arise from a strong local Ising anisotropy [4,5]. The magnetic moment per ion for a spin 1/2 Ising system can be estimated [6] and the calculated behavior is also shown in figure 3 for S=1/2 and g=16.5. We estimate the near neighbor exchange between the Ising moments under the assumption that the contribution to θ deduced from Curie Weiss fits to high temperture inverse susceptibility data comes from exchange interactions only and the contribution from dipolar interactions averages to zero for spherical grains [7]. This give J_{nn} = -0.9K and -1.9K for the Ho and Dy pyrochlore systems. The dipolar energy D_{nn} between the rare earth ions is estimated to be about 2.4 K, and the effective energy scale $J_{eff}=J_{nn}+D_{nn}$ as defined by

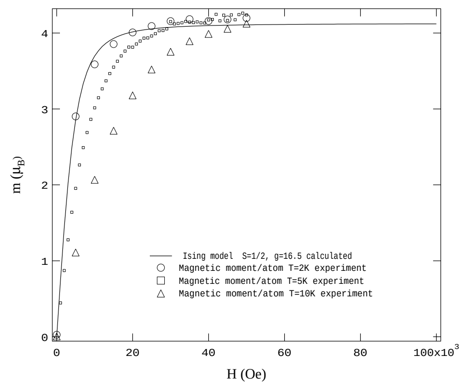

Fig. 3. Isothermal magnetic moment per magnetic ion observed for $Dy_2Ru_2O_7$ pyrochlore. The calculated values for S=1/2 g=16.5 for a two state Ising model as also shown for comparison

Bramwell and Gingras [1] therefore comes out to be positive for both the systems.

3. Conclusions

The magnetic properties of the $Ho_2Ru_2O_7$ and $Dy_2Ru_2O_7$ pyrochlores studied in the temperature range 2K-350K show single ion Ising anisotropy, give an effective ferromagnetic exchange between the rare earth moments, and the low temperature behavior of rare earth ions is independent of the antiferromagnetic ordering of Ru moment occuring at higher temperatures. These characteristics are similar to the other canonical spin ice systems and need to be further investigated by low temperature AC susceptibility, specific heat, and neutron scattering to confirm the phenomenon of spin ice magnetism in them.

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