SPECIFIC HEAT STUDIES OF MAGNETIC TRANSITIONS IN RARE-EARTH METALS

by

KASTHURI ACHCHI KANKANAMALAGE DON
DHARMAWANSA DAYARATHNA JAYASURIYA

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ABSTRACT

The magnetic transitions of the heavy rare-earth metals gadolinium, terbium, dysprosium and holmium have been examined by specific heat measurements. The measurements were carried out on high purity (>99.7 at%) single crystals of gadolinium (1.236 g) and terbium (3.734 g) over the temperature range 200 K to 400 K and on high purity (>99.7 at%) single crystals of dysprosium (0.6782 g) and holmium (28.1506 g) over the temperature range 77 K to 400 K. Measurements were also undertaken on a polycrystalline dysprosium sample (43.2495 g) over the temperature range 77 K to 400 K.

Conclusive evidence for the discontinuous nature of the ferromagnetic to helical antiferromagnetic transitions in terbium and dysprosium at their Curie temperatures (Tb: T_C=221.45 K, Dy: T_C=91.33 K) has been obtained for the first time from specific heat measurements. The values of the latent heats at T_C of terbium and dysprosium are found to be (13.6±0.06) $Jmol^{-1}$ and (39.1±1.5) $Jmol^{-1}$ respectively. Temperature hysteresis was observed in the specific heat of both terbium and dysprosium at their Curie temperatures; the values determined are (0.24±0.03) K and (1.2±0.4) K respectively.

The specific heat data around the helical antiferromagnetic to paramagnetic transition at the Nëel temperature T_N of terbium (229.89 K), dysprosium (179.90 K) and holmium (132.245 K) and the data around the ferromagnetic to paramagnetic transition at the Curie temperature T_C of gadolinium (293.68 K) have been analysed in terms of the equation

$$C^{\pm} = (A^{\pm}/\alpha^{\pm})|t|^{-\alpha^{\pm}}(1+E^{\pm}|t|^{x^{\pm}}) + B^{\pm} + D^{\pm}t$$

where $t=(T-T_N)/T_N$ or $t=(T-T_C)/T_C$. We find that the scaling law $\alpha^{+}=\alpha^{-}$ is valid for the critical data of these rare-earths. In order for the condition $B^{+}=B^{-}$, predicted by theory, to be satisfied, we find it

necessary to include the confluent singular term in E in our fits for terbium and dysprosium. However, for the cases of holmium and gadolinium, we find that the condition $B^{+}=B^{-}$ is not applicable for the critical data.

The values of the parameters $\alpha=\alpha^{+}=\alpha^{-}$ obtained for terbium, dysprosium, holmium and gadolinium are 0.21±0.03, 0.24±0.02, 0.27±0.02 and -0.32±0.02 respectively. The values of α that we obtain are not close to the predictions of renormalisation group theory for magnetic systems with short-range interactions. These non-classical values of the critical indices could be associated with the long-range nature of the indirect exchange interaction in the rare-earth metals or with the incommensurate nature of the ordered phase. Furthermore, the results of this present study suggest that the critical exponents for incommensurate systems, such as for the rare-earths, are non-universal.

Cross-overs from the critical region to a region with different behaviour are observed in terbium, holmium and gadolinium above the critical point, but not below it. The possibility is suggested that these cross-overs could be associated with the relative sizes of the range of the indirect exchange interactions and the range of the spin correlations.

In addition, specific heat measurements have also been carried out on two polycrystalline samarium samples in order to study the magnetic transition at about 106 K. The Morin transition in natural haematite samples has been examined by specific heat and Mössbauer measurements. The Mössbauer measurements indicated a change in the effective magnetic field at the nucleus around the Morin temperature of ~260 K, whereas no anomaly associated with the transition from antiferromagnetism to weakly ferromagnetism at the Morin point is observed; this is consistent with the spread of the transition around the Morin temperature.