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Magnetization curves in MnRhP around the Curie temperature

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Abstract

Measurements of detailed magnetization curves have been made in a hexagonal Fe_2P-type ternary intermetallic compound, MnRhP around the Curie temperature by using a sample-subtracting type magnetometer. For the critical exponents $\beta=0.43$ and $\delta=2.67$ were obtained. Though this material is called nearly two-dimensional ferromagnet, the temperature dependence of the spontaneous magnetization determined from Arrott plots has no two-dimensional character. This tendency is different from the case of Cu_2Sb-type intermetallic compounds, MnZnSb and MnGaGe in which two-dimensional character was observed in β.

Keywords: Magnetically ordered materials; MnRhP; Magnetic phase transition; Critical phenomena

1. Introduction

Numbers of investigations have been made in Mn-based intermetallic compounds due to their variety of states in both magnetic and crystal structures. Among these compounds, some Mn atoms have itinerant electron character, while others show localized state. These compounds show almost all magnetic behaviours: ferromagnetism, antiferromagnetism, ferrimagnetism and paramagnetism.

In the case of Cu_2Sb-type intermetallic compounds, MnZnSb and MnGaGe, Mn atoms form ferromagnetic layers perpendicular to the *c*-axis. Between each Mn-layer there are two non-magnetic layers of Zn+Sb or Ga+Ge atoms. Hence, those compounds are called nearly two-dimensional ferromagnets. However, no two-dimensional character had been observed in those compounds until the detailed investigation of the critical phenomena made by the present authors [1,2]. In these compounds the two-dimensional character can only be seen in the temperature dependence of the spontaneous magnetization around the Curie temperature where the ferromagnetic Mn–Mn coupling along the *c*-axis through two non-magnetic layers becomes weaker than the direct coupling in the (a,b)-plane.

A ternary intermetallic phosphide compound, MnRhP has a hexagonal Fe_2P-type crystal structure as shown in Fig. 1. In this compound P atoms form tetrahedral and square-based pyramids and Mn atoms occupy the pyramidal sites, while Rh atoms enter into the tetrahedral sites. This compound is a ferromagnet with the Curie temperature around 400 K and with the magnetic moment of 3 μ_B per molecule, which is mainly carried by the Mn atoms [3–6]. When we see this crystal along the *c*-axis, Mn+P atoms form ferromagnetic layers. Between each Mn+P layer there is a Rh+P atom-layer. Hence, this compound is also considered to be a nearly two-dimensional ferromagnet. It seems interesting to investigate the critical phenomena around the Curie temperature and to see, if any, two-dimensional character in this compound.

2. Experiments

Polycrystalline specimens of MnRhP were prepared by mixing pure original materials of Mn, Rh and P and annealing after being sealed in evacuated silica tubes as mentioned in Ref. [5]. The tubes were kept at 400°C for a

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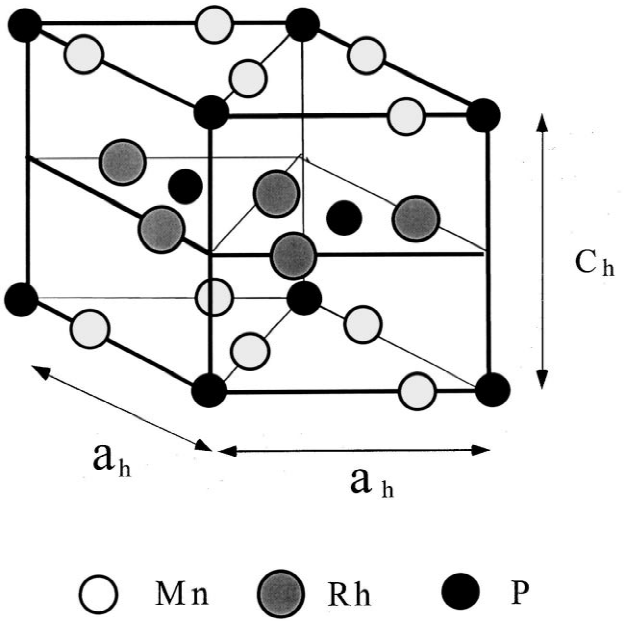

Fig. 1. Fe_2P-type crystal structure of MnRhP.

day, and then annealed at 850°C for 3 days. Finally they were quenched in water. The crystal structure of a Fe_2P-type was confirmed by measuring X-ray diffraction patterns.

Detailed measurements of magnetization curves around the Curie temperature have been made in MnRhP by using a subtracting-sample magnetometer. A magnetometer of this type is extremely useful to observe a detailed magnetization curve and to analyze the magnetization process. The temperature of the specimen during measurement of a magnetization curve was stabilized by using a PID-heater controller.

3. Results and discussion

Observed magnetization curves in MnRhP are shown in Fig. 2. As has often been pointed out by many authors, it is not possible to determine the spontaneous magnetization directly from the M–H curves shown in this figure due to the gradual curvature. Therefore, the observed magnetization curves were analyzed by using the so-called Arrott plot method. The results are shown in Fig. 3. By using this plot, it becomes possible to determine the spontaneous magnetization. The Curie temperature can also be determined from this plot to be the temperature at which the extrapolated line passes through the origin. In the present case T_C was determined to be 379 K. The spontaneous magnetization thus determined was plotted in Fig. 4 as a function of temperature. From this figure it is seen that the spontaneous magnetization becomes linear to $(T_C - T)$ if plotted in a logarithmic scale,

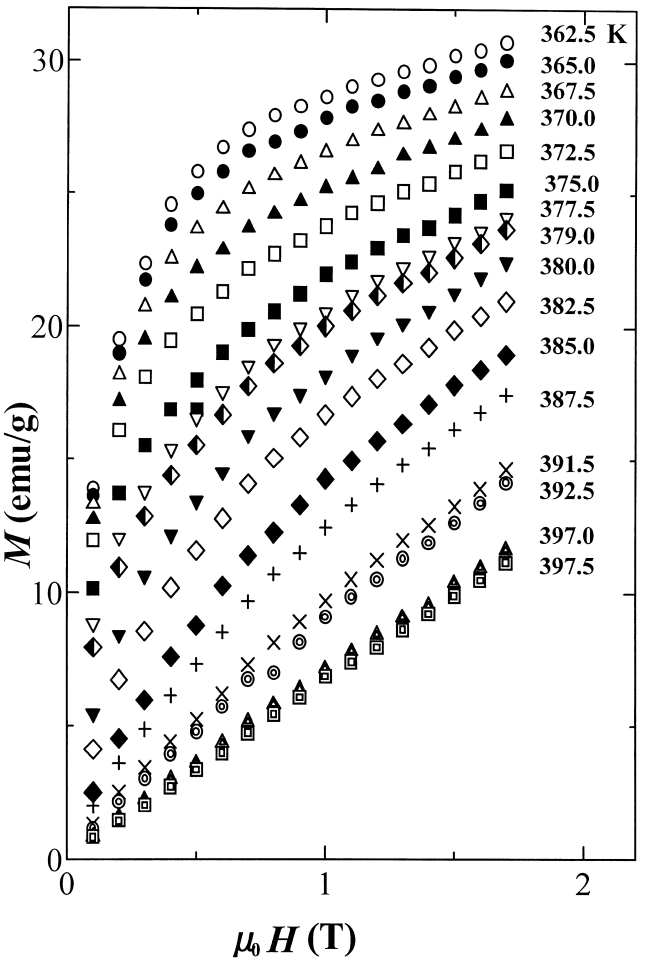

Fig. 2. Magnetization curves in MnRhP around the Curie temperature.

$$M_s = B(T_C - T)^{\beta} \quad (1)$$

From the slope of this plot the critical exponent β can be determined. In the present case, $\beta = 0.43$ was obtained, which is far larger than the theoretical value of 0.125 for a two-dimensional Ising ferromagnet, but is rather close to the theoretical value of 0.5 for a three-dimensional ferromagnet. This fact means that the ferromagnetic state of this material is not two-dimensional as seen in MnZnSb and MnGaGe, but three-dimensional as in the case of usual metallic ferromagnets. This result indicates that the ferromagnetic exchange interaction between Mn–Mn atoms along the *c*-axis through a Rh+P layer is as strong as the direct interaction of Mn–Mn atoms in the (a,b)-plane. This result can be understood by considering the fact that in the case of MnRhP, each magnetic plane is separated by only one single sheet of Rh+P layer, while in the case of MnZnSb and MnGaGe, it is separated by double sheets of non-magnetic layers.

The observed magnetization curve at the Curie temperature is plotted in Fig. 5 in a logarithmic scale. The slope of this plot

$$M = DH^{1/\delta} \quad (2)$$

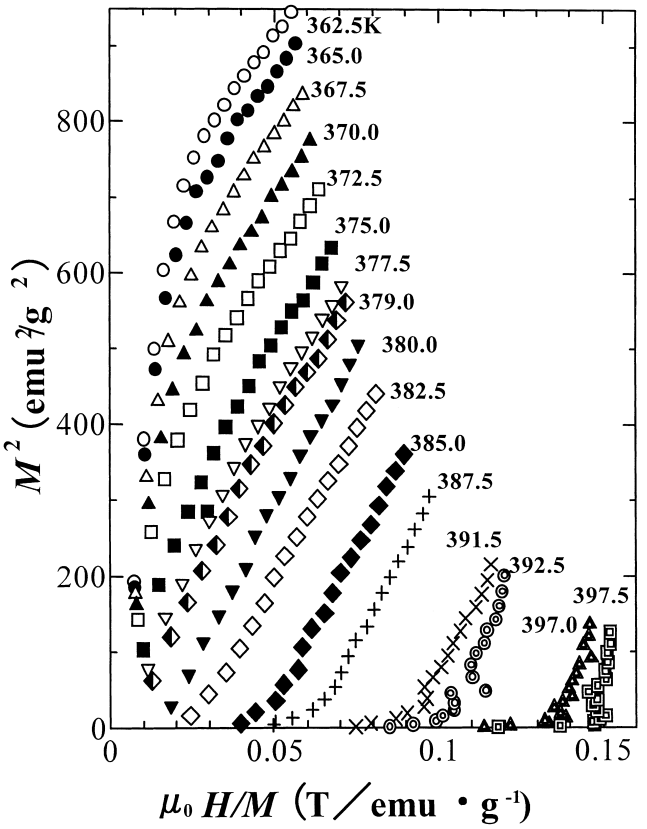

Fig. 3. Arrott Plots (M^2-H/M plots) of the magnetization curves in MnRhP around the Curie temperature.

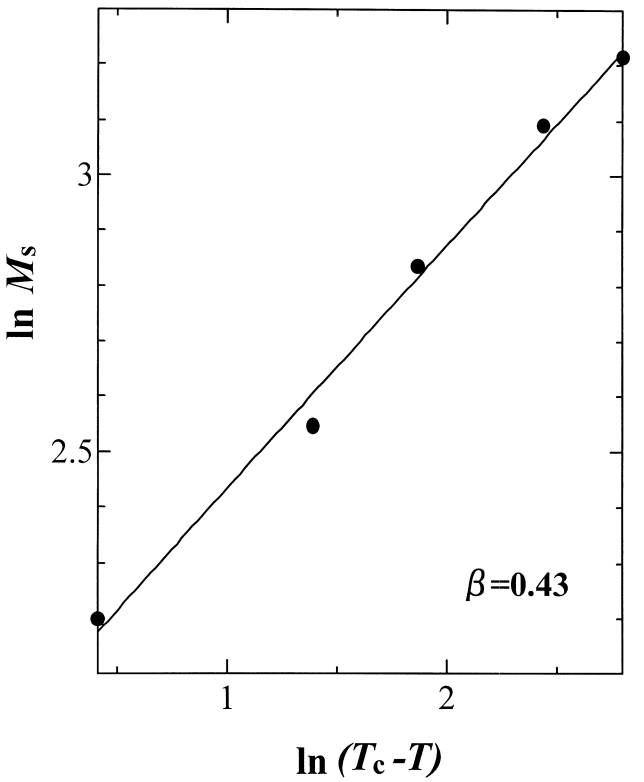

Fig. 4. Spontaneous magnetization M_s plotted against (T_C-T) in a logarithmic scale.

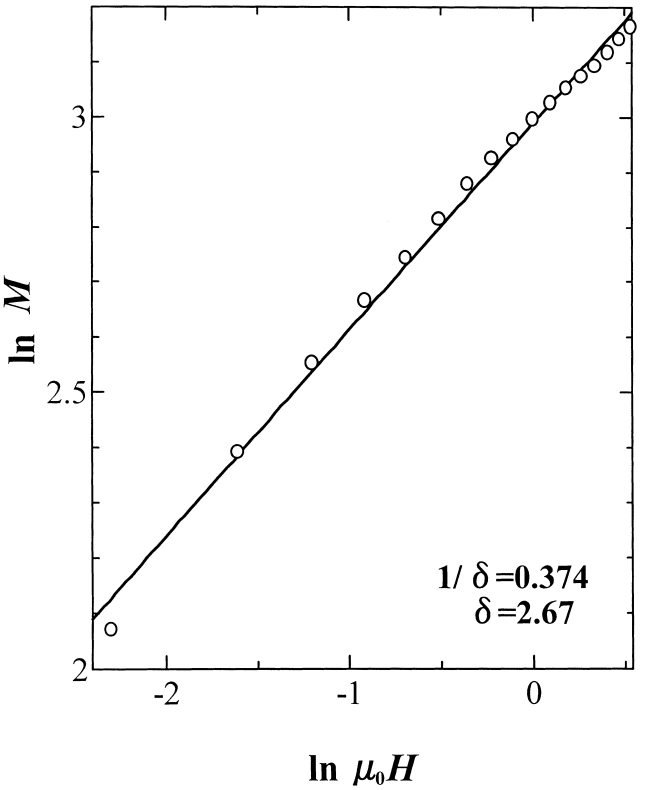

Fig. 5. Magnetization curve of MnRhP at $T=T_C$ in a logarithmic scale.

gives the critical exponent, $\delta=2.67$. This value is again close to the value for a three-dimensional ferromagnet. In the case of MnZnSb and MnGaGe, the values of δ are also close to the three-dimensional value [1,2] and do not show any two-dimensional character. The reason why even in such nearly two-dimensional ferromagnets δ does not show any two-dimensional character is that when an external field is applied, several magnetic domains, originally two-dimensional at $T=T_C$ and $H=0$, are immediately connected into three-dimensional blocks.

Observed temperature dependence of the susceptibility χ above the Curie temperature is plotted in Fig. 6 in a logarithmic scale. As seen in this figure, the relation

$$\chi = C(T - T_C)^{-\gamma} \tag{3}$$

does not hold in this case. If we take the initial slope, then $\gamma=0.15$ is obtained. This value is very small compared with the calculated ones, 1 and 1.75 from the molecular field theory and the two-dimensional Ising model, respectively. The values of γ in MnZnSb and in MnGaGe are also smaller than the calculated one either from the two-dimensional or three-dimensional model [1,2]. The small values obtained for γ in these materials may be due to some effect of spin fluctuation.

It seems worth emphasizing that the Mn-magnetic moment of the materials in which a two-dimensional character has been seen up to date is about 1.5 μ_B which is

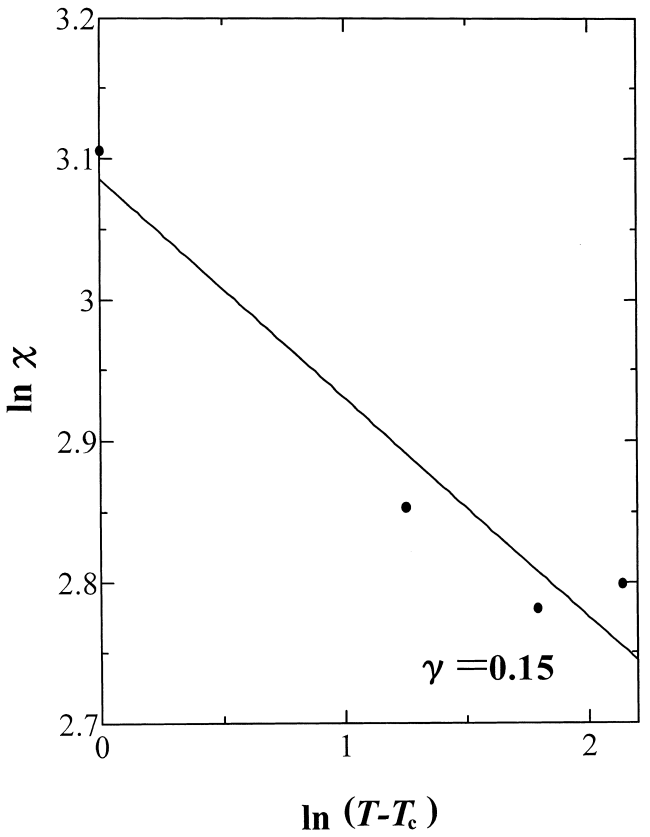

Fig. 6. Susceptibility-temperature curve of MnRhP in a logarithmic scale above the Curie temperature.

not fully polarized and hence, is itinerant-electron type, while in the case of fully polarized localized electron type such as the present material, MnRhP, no two-dimensionality has been observed even though it looks nearly two-dimensional judging from its crystal structure.

4. Conclusions

The critical exponents β and δ in a hexagonal ternary intermetallic compound MnRhP were determined through measurements of magnetization curves around the Curie temperature. In this material Mn+P atoms form a layered structure and each Mn-layer is separated by a non-magnetic Rh+P layer, and hence, two-dimensionality had been expected in the temperature dependence of the spontaneous magnetization as seen in Cu_2Sb-type intermetallic compounds, MnZnSb and MnGaGe. However, no two-dimensional character was seen in either β or δ in MnRhP. This result can be understood by considering the fact that in the case of MnRhP, each magnetic plane is separated by only one single sheet of Rh+P layer, while in the case of MnZnSb and MnGaGe, it is separated by double sheets of non-magnetic layers.

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