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LETTER TO THE EDITOR

Suppression of the Curie–Weiss paramagnetism seen above the Néel transition in dilute CrV alloys

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Abstract. The temperature dependence of the AC magnetic susceptibility of antiferromagnetic Cr–x% V ($x = 0, 0.1, 0.67, 1.0, 1.5$) has been investigated in the vicinity of the Néel transition. The behaviour of Cr–0.1% V is similar to that reported previously for the alloys containing 0.2 and 0.4% V, in that the susceptibility above the Néel transition has a component with a temperature dependence that obeys the Curie–Weiss (CW) law. This CW paramagnetism was not however seen in the samples containing higher concentrations of V. The DC susceptibility of Cr–0.2% V was also measured in fields of 2.0, 6.5 and 20.0 kOe, and the high field was found to suppress the CW paramagnetism.

Local magnetic moments are present in some Cr alloys with Fe [1–3], Co [2], Mn [4] and V [5–7]. All such alloys exhibit Curie–Weiss (CW) paramagnetism above the Néel temperature T_N, while the susceptibility of dilute CrFe alloys obeys a CW law also in the spin-density-wave (SDW) phase. In CrV alloys, however, the component of the susceptibility that has the characteristic CW temperature dependence is only a small part of the total susceptibility. Fe, Co and Mn are of course magnetic metals, and the CW paramagnetism in their Cr alloys is usually attributed to existence of local moments on the impurity atoms. The same may be the case in the CrV alloys, with the V atom carrying a magnetic moment in the paramagnetic Cr host matrix. The CW component of the susceptibility in CrV alloys is observed only above T_{CW}, a temperature previously defined [7], which is somewhat higher than T_N. It is possible that the onset of CW paramagnetism at T_{CW} is associated with the formation of a local spin-density wave around the V impurities [8, 9]

In this letter we present measurements of the AC magnetic susceptibility of samples Cr–x% V ($x = 0, 0.1, 0.67, 1.0$ and 1.5; all concentrations of V are in atomic per cent in this paper) together with previous results [7] for $x = 0.2$ and 0.4. A CW component of the susceptibility is observed for $x = 0.1, 0.2$ and 0.4, but not for $x = 0.67, 1.0$ or 1.5. Measurements of the DC magnetic susceptibility, χ_{DC}, in Cr–0.2% V, carried out in a field $H = 2.0$ and 6.5 kOe, show the CW paramagnetism above the Néel transition as in previous results at $H = 1.0$ kOe [6], whereas for $H = 20.0$ kOe it is completely suppressed.

The CrV samples studied were mostly polycrystals prepared by arc melting, but the samples containing $x = 0.67$, 1.0 and 1.5% V were single crystals prepared by a float-zone

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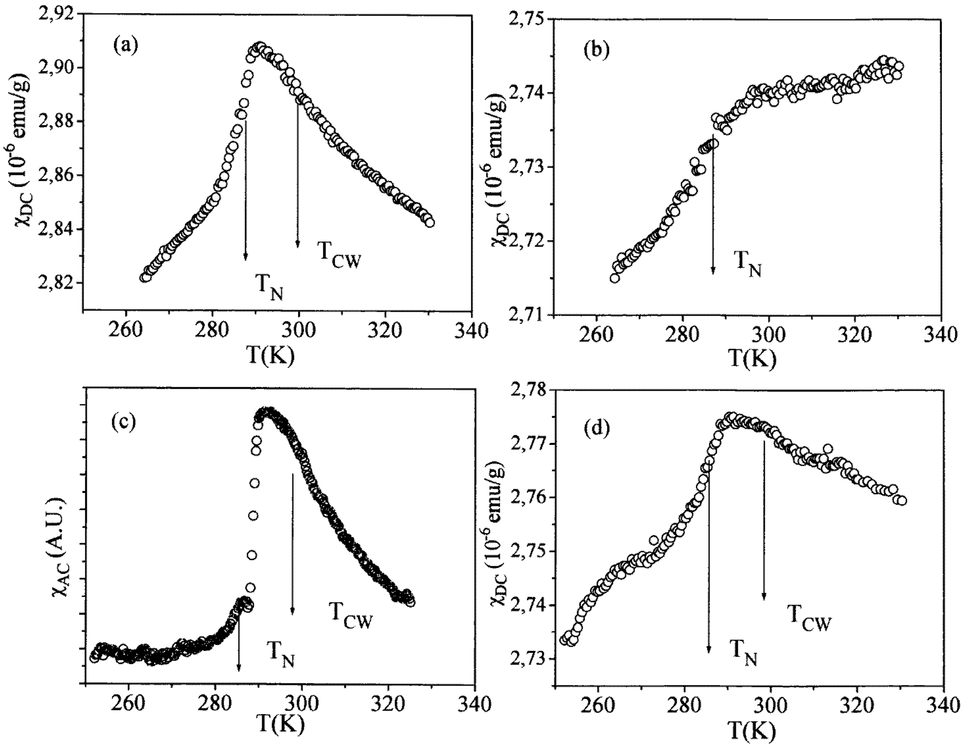

Figure 1. Temperature dependence of the magnetic susceptibility of Cr–0.2% V: (a) χ_{DC}(T) obtained with the SQUID magnetometer with a measuring field $H = 2.0$ kOe; (b) $\chi_{DC}(T)$ with measuring field, $H = 20.0$ kOe; (c) $\chi'(T)$ obtained in AC susceptometer with magnetic field of 15.0 Oe [7]; (d) $\chi_{DC}(T)$ with measuring field, $H = 6.5$ kOe.

method that combines radio-frequency and resistance heating [10] and had been thoroughly characterized in several previous experiments [11–13]. Identical behaviour was observed in single-crystal and polycrystal samples of the same composition.

The AC measurements were carried out with an AC susceptometer [14] based on a modified Hartshorn bridge [15–17]. The experiments were performed with an AC magnetic field, $h_{AC} = 7$ Oe, at a frequency of 37.4 Hz, in zero DC magnetic field. The system provides simultaneous detection of the in-phase signal, which is proportional to χ', and its quadrature, which in this case is proportional to the reciprocal of the AC resistivity ρ_{AC} [18]. These are quite distinct physical quantities, and each reveals the magnetic features of the system under study in its own characteristic manner [7].

The χ_{DC} measurements were made in a Quantum Design SQUID magnetometer, model MPMS5. In each run the sample temperature was decreased through T_N in zero field. The magnetic field was then applied and the measurements taken as a function of increasing temperature. Each χ_{DC} point results from an average of two scans taken over a 3 cm length of the sample by the SQUID sensor.

Figure 1 shows several different measurements for the Cr–0.2% V sample. Figure 1(a) shows the temperature dependence of χ_{DC} obtained in the SQUID magnetometer with a measuring field $H = 2.0$ kOe. The CW behaviour is clearly seen above $T_{CW} \approx 300$ K, in agreement with previous results [7]. In contrast, figure 1(b), measured in the SQUID

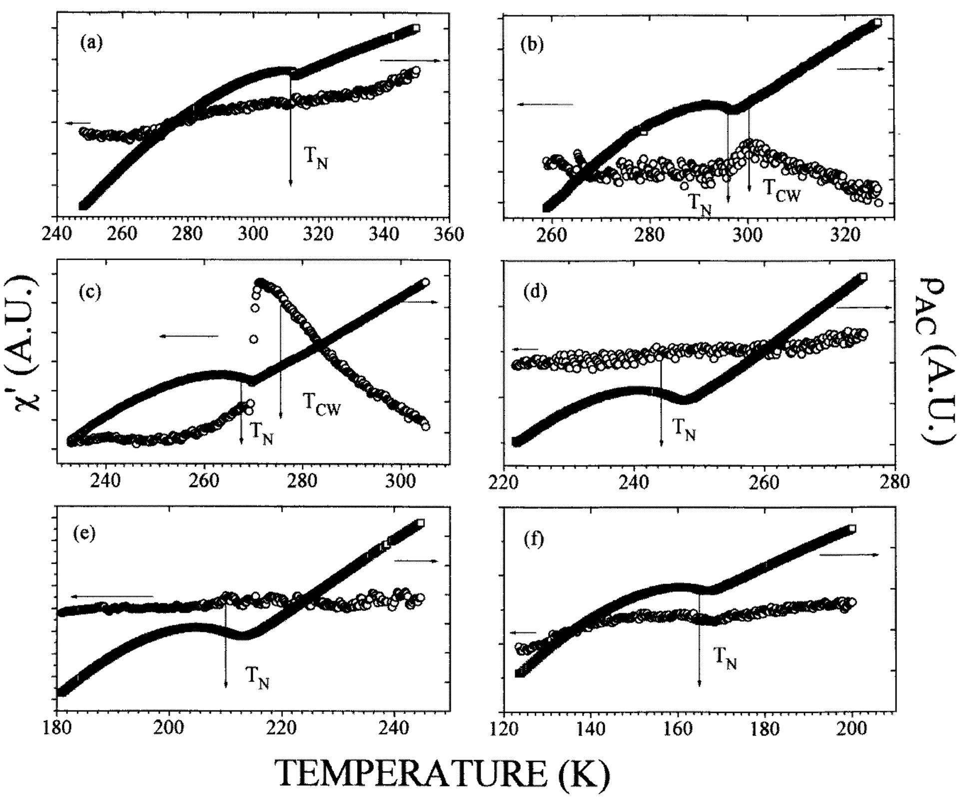

Figure 2. Temperature dependence of the two components of the AC magnetic susceptibility, $\chi'(T)$ and $\rho_{AC}(T)$, obtained in the AC suscpetometer with an AC measuring field of 7.0 Oe at frequency 37.4 Hz for Cr–x% V: (a) $x = 0, T_N = 311$ K; (b) $x = 0.1, T_N = 296$ and $T_{CW} = 298$ K; (c) $x = 0.4$, $T_N = 268$ K and $T_{CW} = 273$ K [7]; (d) $x = 0.67$, $T_N = 244$ K; (e) $x = 1.0$, $T_N = 210$ K; (f) $x = 1.5$, $T_N = 165$ K

magnetometer at 20.0 kOe, shows no CW paramagnetism, and is similar to the results for pure Cr [6]. This behaviour, suggesting that large fields inhibit the appearance of local moments, is the first reported for Cr alloys. Figure 1(c) has been previously published [7] and shows χ_{AC} measured with an AC excitation field of 15 Oe. Again we see a component of the susceptibility above the Néel transition having the characteristic CW temperature dependence. Figure 1(d) shows that the CW paramagnetism is still seen in the SQUID data in a measuring field $H = 6.5$ kOe. Measurements by Hedman [19] using the Faraday method, also with a measuring field of 6.5 kOe, on a sample of Cr–0.2% V cut from the same rod as our sample showed no sign of CW paramagnetism above the Néel transition. We have no explanation for this failure of the Faraday method to reveal the CW component of the susceptibility in the paramagnetism phase. It should be noted, however, that most of the experimental data for the temperature dependence of the susceptibility in Cr alloys (see table V in [1]) were obtained by the Faraday method, and a careful re-examination with a SQUID magnetometer may show that other ‘non-magnetic’ impurities besides V introduce a CW component into the temperature dependence of the susceptibility above the Néel transition.

Figure 2 shows the simultaneous results obtained from the AC susceptibility for $\chi'(T)$ and $\rho_{AC}(T)$ for samples of all our CrV alloys (including Cr–0.4% V reported previously[7]), except Cr–0.2% V, which is shown in figure 1. There is a complete agreement between $\rho_{AC}(T)$ and the temperature dependence of the resistivity measured by the four-probe technique [1]. The behaviour in all the CrV alloys is essentially the same as in pure Cr.

The AC susceptibility $\chi'(T)$ in pure Cr (figure 2(a)) increases with temperature over the whole range of measurement, exhibiting a small inflection at T_N. In figure 2(b) for Cr–0.1% V a small peak appears with its maximum at $T_{CW} = 298$ K, about 2–3 K above T_N. CW paramagnetism starting at $T_{CW} = 273$ K, about 5 K above T_N, also occurs in Cr–0.4% V, as seen in figure 2(c) [7], but this component of the susceptibility is absent for $x = 0.67$, 1.0 and 1.5% V (figures 2(d)–(f)).

There is a discrepancy between the present results and those of Kondorskii *et al* [5], who observed that the susceptibility decreases with increasing temperature above the Néel transition in CrV alloys containing $x = 0.58$, 1.04 and 1.58% V. They found however, a broad Néel transition having a width of about 50 K, which suggests that their samples were inhomogeneous, so the explanation for the apparent discrepancy may be that some part of their samples contained less than 0.4% V.

Thus, in summary, the CW paramagnetism above the Néel transition in dilute CrV alloys disappears at some concentration of V in the range between 0.4 and 0.67% V, while the measuring field, when increased from 6.5 to 20.0 kOe, suppresses the CW paramagnetism in Cr–0.2% V.

The existence of CW paramagnetism above the Néel transition in dilute CrV alloys is still not understood. Hill *et al*, who first reported this interesting effect [6], attributed it to the appearance of local moments on the V atoms, but alternatively one might seek an explanation in terms of a local spin-density wave. Buzdin *et al* [8] consider the formation of a local SDW at the impurity and find that the local SDW state exists over some temperature interval above the bulk Néel temperature T_N, with a transition to the paramagnetic phase at some higher temperature T_L. In the local SDW phase between T_N and T_L the net moment at the impurity is predicted to show CW paramagnetism. Our results, on the other hand, show CW paramagnetism appearing at T_{CW}, a temperature somewhat above T_N.

The present results provide additional circumstantial information about the effect that should help in finding its explanation. First, the CW paramagnetism in Cr–0.2% V is suppressed by a field of 20 kOe (figure 1(b)), but not 6.5 kOe. Secondly, the CW paramagnetism disappears somewhere between $x = 0.4$ and 0.67% V in Cr (figures 2(c) and 2(d)).

An alternative explanation [7] for the disappearance of the CW paramagnetism at higher concentrations of V is suggested by the theoretical work of Hattox *et al* [20], who found that, when the lattice spacing in pure V reaches a critical value of 1.25 times its normal value, local magnetic moments appear. This theory has explained the temperature dependence of $\chi(T)$ for the metallic compounds Au_4V [21] and Al_3V [22], and also for multilayers of Au and V [23, 24].

The effect of the measuring field on the susceptibility in CrV alloys is being studied in detail, and a study of the relaxation of the magnetic response is also under way.

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