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Magnetic field dependence of the Curie–Weiss paramagnetism in CrV alloys

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The determination of the magnetic properties of antiferromagnetic Cr alloys requires careful consideration of the influence of the applied magnetic field. In this work we show that alloys of Cr-x at. % V present a Curie–Weiss paramagnetism above the Néel temperature, which is suppressed by a characteristic field H_L. Samples with $x=0.1$, 0.2, and 0.4 were investigated through measurements of the magnetic susceptibility as a function of temperature, for different values of the magnetic field. A magnetic phase diagram showing the characteristic line H_L vs x at. % V is proposed. [S0021-8979(97)27108-2]

I. INTRODUCTION

Chromium is an itinerant antiferromagnet below its Néel temperature (T_N), this phase being well described by spin-density waves (SDW). Dilute alloys of Cr with ferromagnetic (Fe and Co)[1,2] and antiferromagnetic (Mn)[3] metals, exhibit local magnetic moments. When one introduces these impurities in Cr, the temperature dependence of the magnetic susceptibility shows a Curie–Weiss (CW) behavior below and above T_N. However, for alloys with V,[4–6] Si,[7] Rh,[8] Mo and W,[9] this behavior is present only above T_N. In particular for dilute CrV alloys, the magnetic susceptibility develops a CW component only above T_{CW}, a temperature previously defined,[5] which is somewhat higher than T_N. The nature of the magnetic moment responsible for this behavior is not known yet. It is possible that the CW paramagnetism above T_{CW} could be associated with the formation of local spin-density waves around V impurities.[5,10,11]

It has been previously reported[6] that the CW paramagnetism is absent for impurity concentrations greater than 0.4 at. % V, and that a magnetic field of 20 kOe is enough to inhibit this behavior for Cr-0.2 at. % V. This article presents the temperature dependence of the dc magnetic susceptibility, $\chi_{DC}(T)$, of antiferromagnetic Cr-x at. % V ($x=0.1$, 0.2, 0.4) samples measured under different magnetic fields, which allowed the determination of the critical field (H_L) above which the CW behavior is suppressed in these alloys. A magnetic phase diagram (H_L vs x at. % V) is proposed for these alloys, with the critical line $H_L(x)$ enclosing the CW phase.

II. EXPERIMENTAL DETAILS

The CrV samples studied are highly homogeneous polycrystals prepared by arc melting, which has been thoroughly characterized in several previous experiments.[6,12,13]

The $\chi_{DC}(T)$ 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 $\chi_{DC}(T)$ point results from an average of two scans taken over a 3 cm length excursion of the sample through the SQUID sensor.

III. RESULTS AND DISCUSSION

Figure 1 shows the temperature dependence of $\chi_{DC}(T)$ for the Cr-0.1 at. % V sample, at fields (a) $H=0.1$ kOe, (b) 1.0 kOe, (c) 2.0 kOe, and (d) 20.0 kOe. For curve (a) the CW behavior is clearly seen above $T_{CW}\approx 298$ K, in agreement with previous results,[6] as well as a characteristic jump around $T_N=296$ K. In (b) the jump around T_N is smaller, however the CW paramagnetism is still present. In (c) the CW response is no longer observed suggesting that the applied field is sufficient to inhibit the appearance of local moments in this alloy. The curve resembles that obtained for pure Cr.[4] Curve (d) shows $\chi_{DC}(T)$ increasing with temperature, a dependence similar to that previously reported for Cr-0.2 at. % V[6] at the same field. The inset exhibits the reciprocal of $\chi_{DC}(T)$, showing the occurrence of CW paramag-

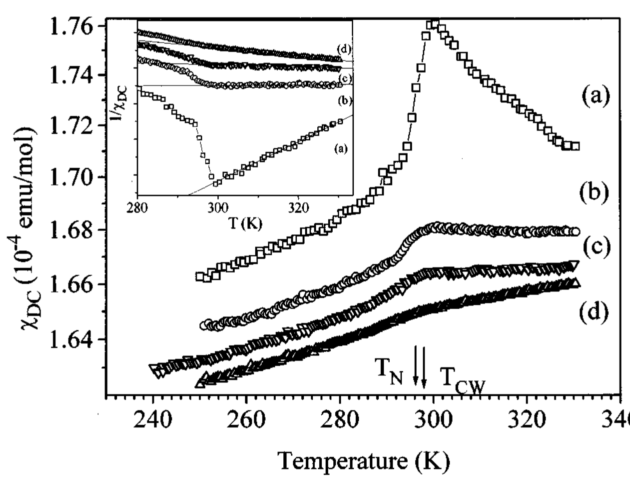

FIG. 1. Temperature dependence of magnetic susceptibility of (a) Cr-0.1 at. % V; (b) $H=0.1$ kOe, (c) $H=1.0$ kOe (d) $H=2.0$ kOe; $H=20.0$ kOe. $T_N=296$ K and $T_{CW}=298$ K. Inset: reciprocal of $\chi_{DC}(T)$ showing the occurrence of CW paramagnetism above T_{CW} for $H\leqslant 1.0$ kOe.

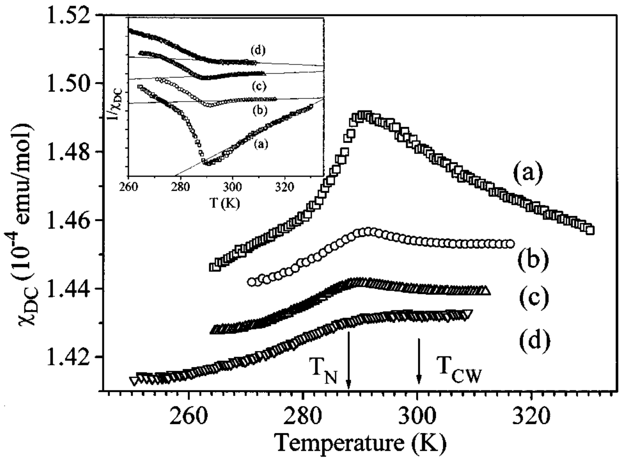

FIG. 2. Temperature dependence of magnetic susceptibility of Cr-0.2 at. % V: (a) $H=2.0$ kOe, (b) $H=8.0$ kOe, (c) $H=10.0$ kOe, (d) $H=15.0$ kOe. $T_N=287.9$ K and $T_{CW}=300$ K. Inset: reciprocal of $\chi_{DC}(T)$ showing the occurrence of CW paramagnetism above T_{CW} for $H \leqslant 10.0$ kOe.

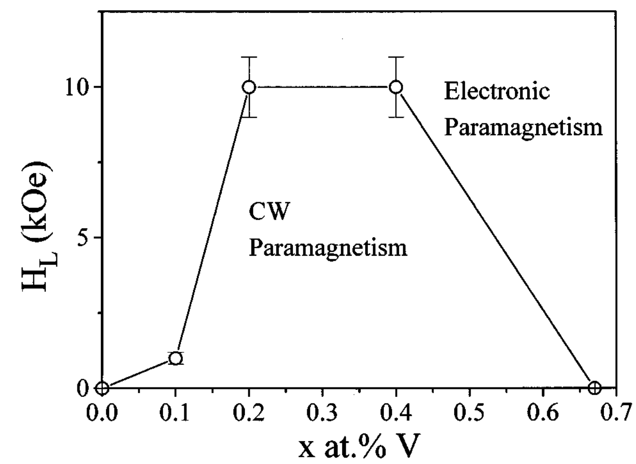

FIG. 4. Magnetic phase diagram of the characteristic magnetic field H_L vs V concentration. The error bars represent the uncertainty in the H_L values, and the dashed straight line is only a guide to the eye. Points for $x=0$ and $x=0.67$ after Ref. 6.

netism above T_{CW} for fields $H \leqslant 1.0$ kOe. The straight lines represent the Curie–Weiss law and are plotted here only as a guide to the eye. The slope of these lines is positive when CW paramagnetism is present.

Figure 2 presents results of $\chi_{DC}(T)$ for the Cr-0.2 at. % V sample. Curve (a) was reported previously[6] and clearly shows the CW behavior above $T_{CW} \approx 300$ K for a field $H=2.0$ kOe. In (b), for a magnetic field $H=8.0$ kOe, the jump is less pronounced than that in (a), anticipating the suppression of local magnetic moments by the field; a similar behavior is observed in (c) with $H=10.0$ kOe. In (d), for $H=15.0$ kOe, clearly the paramagnetic component is not observed anymore, in accordance with previous results for $H=20.0$ kOe.[6]

Figure 3 shows $\chi_{DC}(T)$ of the Cr-0.4 at. % V sample. We observe in curves with $H=2.0$ kOe (a) and $H=10.0$ kOe (b) the same behavior shown by Cr-0.2 at. % V, i.e., CW paramagnetism. Nevertheless, for $H=12.0$ kOe (c) this component of the susceptibility is not present, characterizing the absence of local magnetic moments.

The origin of CW paramagnetism above the Néel transition in dilute CrV alloys is still an open question. Hill *et al.*[4] first reported this effect, which was attributed to the appearance of local moments on the V atoms. One might alternatively propose an explanation in terms of a local spin-density wave,[10] which would form around the impurity site. This local SDW state would exist in some temperature interval above 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 moment at the impurity site would then appear at T_{CW}.

One might say that the magnetic field would cause a decrease in T_L, which would then collapse onto T_N. According to Tugushev,[11] T_L for these materials would occur around 500 K, neglecting magnetic field effects. Unfortunately T_L has not been observed so far, even at 1 kOe for temperatures up to 400 K for Cr-0.2 at. % V and Cr-0.4 at. % V.[4] From what has been presented here, one may conclude that the magnetic field does not affect T_L, but affects the local magnetic moment density. Magnetic fields sufficiently strong may inhibit the formation of local moments. For lower fields the jump in $\chi_{DC}(T)$ is pronounced, i.e., there is a higher density of local moments (or local SDW) around the V atoms. As the field is enhanced, the jump decreases as a consequence of lower moment densities.

The appearance of local magnetic moments depends both on the V concentration and on the magnetic field. Therefore, one can sketch a phase diagram where a critical line $H_L(x)$ separates the CW phase from the ordinary paramagnetic phase. Figure 4 is a proposition of such phase diagram. As previously reported,[6] local moments do not manifest for $x \geqslant 0.67$, even for very low fields (7 Oe), suggesting that $H_L(x)$ vanishes within the interval $0.4 < x \leqslant 0.67$.

One may then conclude that the appearance and the suppression of local moments in Cr-x at. % V alloys are strongly influenced by the applied magnetic field. Studies of other Cr

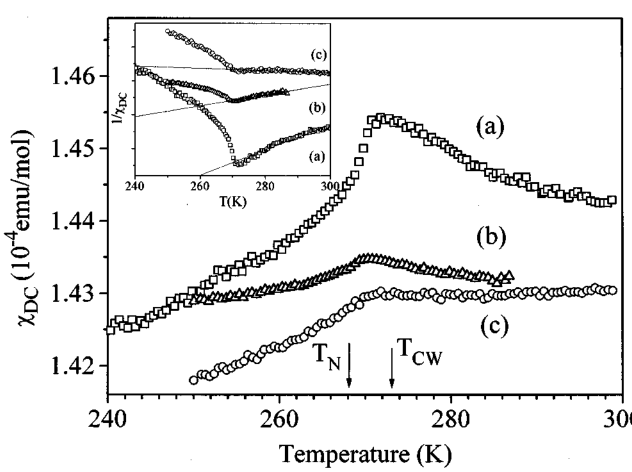

FIG. 3. Temperature dependence of magnetic susceptibility of Cr-0.4 at. % V: (a) $H=2.0$ kOe, (b) $H=10.0$ kOe, (c) $H=12.0$ kOe. $T_N=268$ K and $T_{CW}=273$ K. Inset: reciprocal of $\chi_{DC}(T)$ showing the occurrence of CW paramagnetism above T_{CW} for $H \leqslant 10.0$ kOe.

antiferromagnetic alloys with transition metals might reveal other aspects of the problem, especially when one uses high sensitivity techniques like SQUID magnetometry and ac susceptometry.

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