HIGH MAGNETIC FIELD BEHAVIOR OF IRON IMPURITIES IN CHROMIUM

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Abstract—Mössbauer measurements in ^{57}Fe in dilute FeCr alloys in external magnetic fields up to 140 kOe are presented. The magnetic hyperfine interactions are compared with results obtained by Herbert, Clark and Wilson and are discussed in terms of a model due to Housley and Dash.

THE PRESENCE of small amounts of iron in chromium metal results in a lowering of the Néel temperature along with other anomalous changes in the phase diagram[1, 2]. Susceptibility measurements[1] below the Néel temperature show that the iron sites have associated with them localized magnetic moments of about $1.4\mu_B$ per iron atom and that the iron moments remain paramagnetic down to low temperatures (2°K for 1% Fe in Cr). Paramagnetic resonance of the iron impurities in Cr have shown[3] that the iron moment is in fact localized and that the exchange field acting on the Fe sites at 0°K is ~ 4 kOe. The Mössbauer effect in ^{57}Fe has been used to study the hyperfine interactions at the Fe sites in dilute Cr-Fe alloys[4, 5]; most recently a comprehensive work was reported by Herbert *et al.*[6] who suggested a model for the iron moments in which an exchange field of 225 kOe arising from the chromium spin density wave (SDW) acts on the iron sites, while at the same time there is a partial spin compensation of the Fe moments having a characteristic temperature of 60°K. In this note we present some additional hyperfine field data which are relevant to the problem and suggest that an alternate model due to

Housley and Dash[7] might also be used to understand the hyperfine interactions in this system.

The Mössbauer measurements were made using a ^{57}Co in Cr source vs. a single line absorber and with a 0.5% Fe in Cr absorber vs. a narrow line source. At room temperature the ^{57}Co in Cr source linewidth was 0.23 mm/sec, while the $\frac{1}{2}\%$ Fe in Cr absorber linewidth was 0.31 mm/sec. The measurements may be summarized as follows: (a) the line broadens as T decreases until at 4.2°K the spectrum is consistent with a magnetic hyperfine field distribution centered at about 35 kOe; (b) in an applied field $\mathbf{H}_0$, the spectra become resolved at about $\mathbf{H}_0 = 40$ kOe, the splitting increases with increasing $\mathbf{H}_0$, and the lines remain broad; (c) polarization measurements in the external field show that the total net field at the nucleus $\mathbf{H}_n$ is positive (i.e. in the same direction as $\mathbf{H}_0$). In Fig. 1 we plot the magnitude of field at the nucleus $|\mathbf{H}_n|$ as a function of $|\mathbf{H}_0|$. The source and absorber gave essentially identical results.

We define $\mathbf{H}_{hf}$ by the equation

$$\mathbf{H}_n = \mathbf{H}_{hf} + \mathbf{H}_0;$$

since $H_n > 0$ for $H_0 > 50$ kOe and $|H_n| < |H_0|$, H_{hf} is thus negative, in agreement with Herbert *et al.*[6]. $|\mathbf{H}_{hf}|$ is seen to increase with increasing $\mathbf{H}_0$, and at large $\mathbf{H}_0$ has a value about 12 kOe less than $|\mathbf{H}_0|$.

Fig. 1. Magnitude of the magnetic field at the nucleus H_n plotted as a function of applied magnetic field H_0 at 4.2 K. Above 50 kOe, the sign of H_n is positive; below 50 kOe the sign is not known.

In the model of Housley and Dash[7], an interaction between the nucleus and the SDW is postulated and explicitly included in the expression for the hyperfine interaction:

$$\mathbf{H}_n = \mathbf{H}_0 + \mathbf{H}_{hf} + \mathbf{H}_{SDW}(t, r),$$

where $\mathbf{H}_{hf}$ is now the contribution from the electrons localized on the Fe site and $\mathbf{H}_{SDW}$ is the alloy SDW contribution which has spatial and time variation. In zero external field and above 2 K, $\mathbf{H}_n = \mathbf{H}_{SDW}$, which leads to a nonunique value for $|\mathbf{H}_n|$ and a temperature dependence which does not necessarily follow the Cr magnetization. In large external fields, $\mathbf{H}_n$ includes contributions $\mathbf{H}_0$ and $\mathbf{H}_{hf}$. As noted by Herbert *et al.*[6], at low T the large external field polarizes the Cr SDW so that the wave vectors tend to lie in a plane perpendicular to $\mathbf{H}_0$. Thus $\mathbf{H}_n$ is the vector sum of $\mathbf{H}_{hf}$ which is parallel to $\mathbf{H}_0$, and $\mathbf{H}_{SDW}$ which is roughly perpendicular to $\mathbf{H}_0$. This accounts for the broad lines even at large $\mathbf{H}_0$, and means that the saturation hyperfine field due to the localized electrons $|\mathbf{H}_{hf}^{sat}| \sim -15$ kOe. We note that $\mathbf{H}_{hf}$ is temperature dependent: at $|\mathbf{H}_0| = 130$ kOe and $T = 4.2$ K, $|\mathbf{H}_{hf}| = 12$ kOe; at $|\mathbf{H}_0| = 130$ kOe and $T = 77^\circ\text{K}$, $|\mathbf{H}_{hf}| = 7$ kOe; at $|\mathbf{H}_0| = 0$ kOe and $T =$

298°K , $|\mathbf{H}_{hf}| = 2$ kOe. Furthermore, in an external magnetic field the lines narrow as T increases, just as they do in the absence of an external field.

We feel that this model has two advantages over that proposed by Herbert *et al.*[6]: (1) it tends to agree better with the susceptibility and EPR measurements which show the exchange field acting on the iron sites to be small[1, 3], and (2) it does not require a low temperature spin compensation effect at the iron sites. Thus far, spin compensation has been observed in paramagnetic metals and not much is known about systems with spin polarized conduction bands. On the other hand, application of the Housley-Dash model does require the ad hoc introduction of $\mathbf{H}_{SDW}$. There is some precedence for this as measurements of hyperfine interactions at non-magnetic impurities, such as Sn in Cr[8], also show a distribution of hyperfine fields. An advantage of the Herbert *et al.*[6] model is that it explicitly attempts to fit the zero field hyperfine data.

Measurements of $\mathbf{H}_n$ at very low T (below 1 K) may permit one to choose between the two models. In the Herbert *et al.*[6] model the Fe system is saturated and $\mathbf{H}_n$ should be temperature independent below 1 K, while in the Housley and Dash model the Fe spin system becomes ordered at low T and changes in the hyperfine spectrum should be observed.

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