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FORCED VOLUME MAGNETOSTRICTION OF WEAKLY FERROMAGNETIC $Y(Co_{1-x}Al_x)_2$ COMPOUNDS

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Abstract. – The forced volume magnetostriction of weakly ferromagnetic $Y(Co_{1-x}Al_x)_2$ compounds has been measured to 12 T at 4.2 K and to 5 T at 1.6 K for x near 0.15. Below 9 T the volume magnetostriction is well described by a sum of terms linear and quadratic in the magnetic field.

1. Introduction

There are interesting differences between the magnetism of intermetallic compounds based on iron and those based on cobalt e.g. [1]. The cubic Laves compound YFe_2 for example orders at above 450 K, and at 0 K has been shown to have moments of 1.7 μ_B and -0.45 μ_B at the iron and yttrium sites respectively [2, 3], while YCo_2 exhibits only enhanced paramagnetism. The cobalt compounds are however close to making a magnetic transition. Computer calculations [4] suggest that YCo_2 would make a metamagnetic transition in a field of about 350 T to a state with moments of 1 μ_B and -0.3 μ_B at the cobalt and yttrium sites respectively. While 350 T is not an experimentally accessible field a metamagnetic transition has been observed in $Y(Co_{1-x}Al_x)_2$ for $0.07 < x < 0.11$ in fields up to 35 T [5].

Yoshimura and Nakamura [6] found that $Y(Co_{1-x}Al_x)_2$ compounds with $0.12 < x < 0.20$ show all the classic features of weak itinerant ferromagnetism. The maximum value of the moment per cobalt atom at 0 K (~ 0.14 μ_B) and Curie point (~ 25 K) was found near $x = 0.15$. The effect of the Al substitution is to increase the volume of YCo_2 and to decrease the number of 3d electrons. Both effects tend to make the system ferromagnetic because in YCo_2 the Fermi surface lies in a region where the density of states is decreasing with energy [7].

High field magnetostriction measurements have been reported [8] for $Y(Co_{1-x}Al_x)_2$ in the paramagnetic range $0.095 < x < 0.12$ and show a change of volume proportional to the square of the magnetisation. We now report high field magnetostriction measurements on weakly ferromagnetic samples with x near 0.15 where the spontaneous moment at 0 K has a maximum.

2. Experimental

Polycrystalline discs with diameter 5 mm and thickness 1 mm were spark cut from ingots of $Y(Co_{1-x}Al_x)_2$ with $x = 0.150$, 0.155, 0.165. AC susceptibility measurements were made to check the sharpness of the transition and that the values of the Curie point were similar to those given in [5]. The pressure dependence of the Curie points will be reported elsewhere.

The magnetostriction was measured in directions parallel to and normal to the magnetic field using a capacitance cell and AC bridge with a reproducibility of 3 Å. The field was applied in the plane of the disc. Measurements were made to 12 T at 4.2 K and to 5 T at 1.6 K. No temperature dependence of the magnetostriction was found between 1.6 K and 4.2 K.

The volume change was calculated from

$$\frac{\Delta V}{V} = 2\left(\frac{\Delta \ell}{\ell}\right)_{\perp} + \left(\frac{\Delta \ell}{\ell}\right)_{\parallel}. \quad (1)$$

The field dependence of $\ell_\perp$ and $\ell_\parallel$ is shown in figure 1.

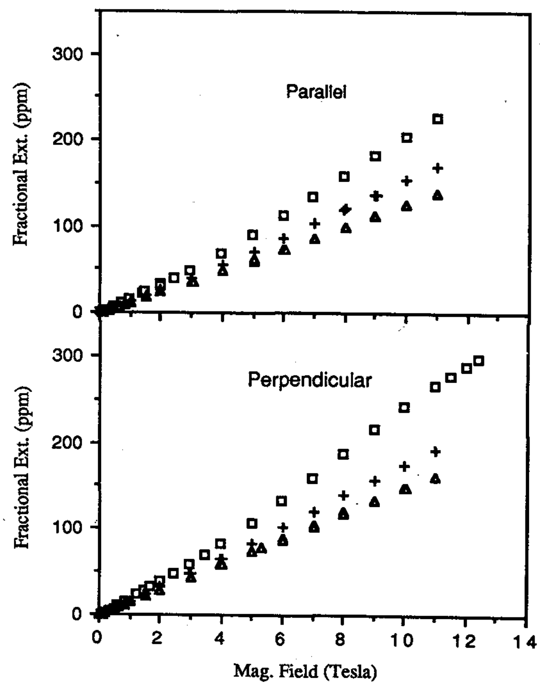

Fig. 1. – The forced linear magnetostriction of weakly ferromagnetic $Y(Co_{1-x}Al_x)_2$ compounds at 4.2 K for $x =$ 0.150 (□), 0.155 (△) and 0.165 (+).

3. Discussion

The length of all three samples of $Y(Co_{1-x}Al_x)_2$ showed a nearly linear variation with magnetic field (B_0) at low field but over the whole range to 12 T showed a distinct curvature, figure 1. A fit was made to the measurements between 0.3 and 9 T of the form

$$\frac{\Delta \ell}{\ell} = aB_0 + bB_0^2 \tag{2}$$

for each direction of the field, table I. There are small deviations from equation (2) above 9 T, particularly for $x = 0.150$, but no abrupt change in slope of $\Delta V / V$ as would be expected if the moment increased suddenly with field as in a metamagnetic type of transition, in agreement with the high field magnetization measurements [5].

Table I. – *The coefficients a and b in equation* (2) *for the forced magnetostriction at* 4.2 K *of* $Y(Co_{1-x}Al_x)_2$ *below* 9 T *for the magnetic field parallel (perpendicular) to the measuring direction.*

x	$10^6 a\,(T^{-1})$	$10^8 b\,(T^{-2})$
0.150	15.3 (18.3)	58 (65)
0.155	12.4 (14.4)	7.0 (5.6)
0.165	12.5 (15.7)	31 (22)

Magnetostriction measurements on other weakly ferromagnetic systems such as Ni_3Al [9] have been stated to have isotropic magnetostriction. We see from table I that for $Y(Co_{1-x}Al_x)_2$ the term linear in B_0 is some twenty per cent greater for $\ell_\perp$ than for $\ell_\parallel$.

The change of volume of YFe_2 at 4.2 K was found (2) to be linear in the field in the range 3-12 T, as would be expected because the magnetization is then independent of field, and was an order of magnitude smaller than for the $Y(Co_{1-x}Al_x)_2$ compounds considered here. The difference in the volume magnetostriction must reflect the greater pressure dependence of the magnetization of $Y(Co_{1-x}Al_x)_2$ compounds since

$$\left(\frac{\partial V}{\partial B_0}\right)_P = -m\left(\frac{\partial \sigma}{\partial P}\right)_{B_0} \tag{3}$$

where m is the mass and V the volume of the sample and σ the magnetization per unit mass. Up to 9 T the magnetization of $Y(Co_{1-x}Al_x)_2$ compounds near $x = 0.15$ is approximately [5] of the form (σ_0 + const. B_0) so the coefficient a in equation (2) may be used to find $\partial\sigma_0 / \partial P$. Taking values of the spontaneous magnetization from [5] we find values of $\partial \ln \sigma_0 / \partial P$ of -0.12, -0.095, -0.13 kbar^{-1} for $x =$ 0.150, 0.155, 0.165 respectively. Taking the reciprocal of ($\partial \ln \sigma_0 / \partial P$) to be a measure of the pressure required to reduce the spontaneous magnetization to zero we see that only ~10 kbar would be sufficient for this purpose in $Y(Co_{1-x}Al_x)_2$ while the lattice expansion [6] due to $x = 0.155$ is equivalent to a negative pressure of ~40 kbar. The $Y(Co_{1-x}Al_x)_2$ system would therefore not exhibit weak ferromagnetism if clamped to the volume of YCO_2.

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