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Itinerant electron magnetism: NMR and magnetization studies in $Y(\text{Co}_{1-x}\text{Al}_x)_3$

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Abstract

The YCo_3 system is characterized by a band structure which results in a magnetic instability of the itinerant subsystem. In such a case, the Co magnetism presents metamagnetic transitions upon application of an external magnetic field in the megagauss range. In the present paper we investigate the effect of substituting Co by Al in YCo_3 . Polycrystalline samples of $Y(\text{Co}_{1-x}\text{Al}_x)_3$ ($x = 0.00, 0.03, 0.05, 0.07$ and 0.10), in the Co-rich site were investigated by means of magnetization $M(H)$, AC susceptibility $\chi_{AC}(T)$ and nuclear magnetic resonance (NMR). The spontaneous magnetization as a function of Al concentration presents an anomalous behavior, which is closely related to $N(E_F, x)$, passing through a maximum at $x = 0.05$, followed by a sharp decrease up to $x = 0.10$. We show that the system becomes a very weak itinerant ferromagnet (VWIF) at $x = 0.10$. NMR results show change in the ^{59}Co hyperfine field value upon Al alloying, which is related to changes in the conduction electrons density. An increase in the number of lines, with respect to YCo_3 , attributed to the ^{27}Al nucleus, was also verified. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Itinerant electrons; Metamagnetism; Intermetallic compounds; NMR; Spin echo and relaxation; Susceptibility; Magnetization

The YCo_3 compound has been studied as a typical itinerant electron metamagnet. The Co magnetic instability is the origin of the two successive metamagnetic transitions (60 and 82 T) observed in the YCo_3 magnetization curve under ultrahigh magnetic fields. At the first transition, the ground state of the Co subsystem goes from a low magnetic state (LMS), to an intermediate one (IMS), and then, at the second transition, to a strong magnetic state (SMS) [1]. Moreover, these transitions can also be observed by employing the large molecular field due to ferromagnetically ordered 4f moments, in the magnetic RCO_3 compounds [2–4] and references therein]. The magnetic moment of the Co subsystem can be changed if the density of states at the Fermi level, $N(E_F)$, is changed, for instance, decreasing the d-electron concentration, through partial Al substitution.

The purpose of the present work is to investigate the itinerant electron magnetism in $Y(\text{Co}_{1-x}\text{Al}_x)_3$ compounds by means of AC susceptibility $\chi_{AC}(T)$, magnetization $M(H)$ and nuclear magnetic resonance (NMR).

The weighed Co–Al content was kept slightly lower than the stoichiometry composition, namely, $Y(\text{Co,Al})_{2.92}$, to avoid precipitation of spurious ferromagnetic phases (Ref. [5] and references therein). Alloying was performed through arc-melting in an argon gas atmosphere. The compounds were annealed at 1050°C for one day (24 h) in a dynamically evacuated quartz tube.

The spin-echo amplitude was measured in a home-made [6] automated coherent pulse NMR spectrometer, at 4.2 K. The magnetization and susceptibility measurements were done in an extraction magnetometer and in a MPMS magnetometer, and an AC susceptometer.

Fig. 1 displays the magnetic susceptibility measurement, χ/χ_{\max} , as a function of temperature, where χ_{\max} is the maximum susceptibility value found. One can observe well-defined transitions, from ordered to non-ordered states. Moreover, for the concentrations $x = 0.05$ and 0.07 a double-peak structure appears. This may be associated with the Hopkinson effect [7,8], as observed by Duc and Oanh [9] in $\text{Ho}(\text{Co}_{1-x}\text{Al}_x)_2$.

Fig. 2 shows the magnetization measurement as a function of the external magnetic field, at 4.2 K, for all Al concentrations. From these data, the spontaneous

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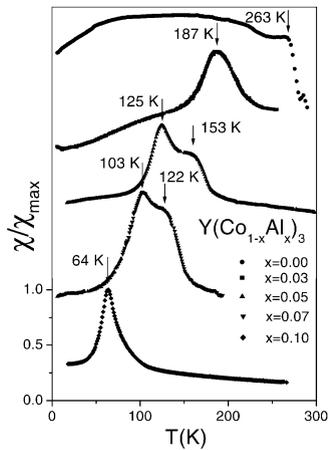


Fig. 1. Temperature dependence of the magnetic susceptibility $\chi_{ac}(T)$ for $Y(Co_{1-x}Al_x)_3$ series, with $0 \leq x \leq 0.10$.

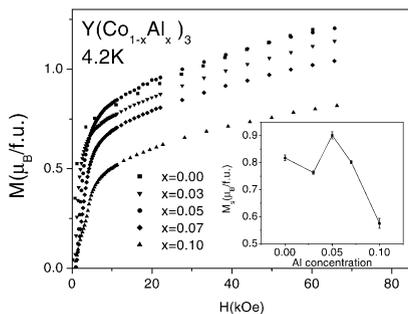


Fig. 2. Magnetization curves, at 4.2 K, for $Y(Co_{1-x}Al_x)_3$. The inset displays the spontaneous magnetization M_s as an Al concentration function.

magnetization M_s , acquired from a linear extrapolation from saturation region to zero field, could be obtained, and is presented in Fig. 2 (inset). This result suggests a maximum close to $x = 0.05$, followed by a sharp decrease up to $x = 0.10$. This may be an indication that the magnetic moment of YCo_3 , an LMS compound, decreases substantially at $x = 0.10$. In order to know which magnetic state this system is migrating to, we have done detailed measurements in $Y(Co_{0.90}Al_{0.10})_3$ compound through Arrott plots (not shown in this paper), for the 5–120 K temperature range.

For a very weak itinerant ferromagnet (VWIF), an expression for Arrott plot, in the particular case $T \ll T_c$, was suggested by Shimizu [10], where the value of $T_c = 63(4)$ K could be determined for that concentration ($x = 0.10$). The value of T_c shown above is approximately the same as that obtained from susceptibility results 64(1) K. The agreement between these results supports the applicability of the framework suggested by Shimizu [10], only valid for a VWIF, for this compound ($x = 0.10$). Therefore, it led us to conclude that the system goes from an LMS in YCo_3 to a VWIF in $Y(Co_{0.90}Al_{0.10})_3$.

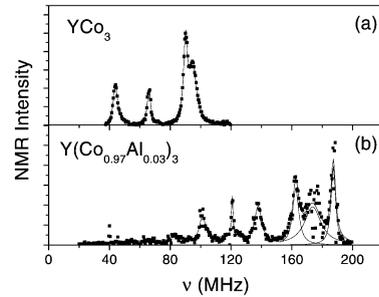


Fig. 3. NMR measurements, at 4.2 K, under zero external field for (a) YCo_3 and (b) $Y(Co_{0.97}Al_{0.03})_3$.

NMR measurements, at 4.2 K, were carried out with the Co-rich compounds ($x = 0.00$ and 0.03), in order to study the hyperfine field behavior at the Co sites [3,4,5] through partial Al substitution. Fig. 3 displays the NMR spectra, under zero external magnetic field, for (a) $x = 0.00$ and (b) $x = 0.03$ compounds. The first one shows only ^{59}Co lines, whereas the second (Fig. 3(b)) displays NMR lines from ^{59}Co and ^{27}Al . In principle, the higher frequency lines (above 100 MHz) observed in Fig. 3(b) could be attributed to ^{27}Al nuclei, since the response of our detection circuit is not flat with the NMR frequency. These lines could appear enhanced even for small amounts of Al. Another possibility would be additional ^{59}Co transition due to an increase of the electric field gradient caused by lattice distortion [11]. Detailed NMR results will be published elsewhere.

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