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Authors
Amato, A
Canfield, PC
Feyerherm, R
et al.

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Zero-field muon spin relaxation studies of low-temperature magnetism in $Yb_xY_{1-x}BiPt$ ($x = 1.0$ and 0.5)

A. Amato[a], P.C. Canfield[b], R. Feyerherm[a], Z. Fisk[b], F.N. Gygax[a], R.H. Heffner[b], E.A. Knetsch[c], D.E. MacLaughlin[d], H.R. Ott[e], A. Schenck[a], J.D. Thompson[b] and U. Zimmermann[a]

[a]*Institut für Mittelenergiephysik der ETH-Zürich, CH-5232 Villigen PSI, Switzerland*
[b]*Los Alamos National Laboratory, Los Alamos, NM 87545, USA*
[c]*Kamerlingh Onnes Laboratory, Leiden University, 2300 RA Leiden, The Netherlands*
[d]*University of California, Riverside, CA 92521-0413, USA*
[e]*Laboratorium für Festkörperphysik, ETH-Hönggerberg, CH-8093 Zürich, Switzerland*

Zero-field muon spin relaxation studies are reported for crystalline $Yb_xY_{1-x}BiPt$ for $x = 1.0$ and 0.5. YbBiPt exhibits an extremely large C_p/T ratio $\gamma \simeq 8\,J/(K^2\,mol\,Yb)$ below $T \simeq 0.2\,K$ and shows evidence for some type of magnetic order below 0.4 K from χ_{AC}. The μSR data are consistent with a highly frustrated spin system segmented into two types of magnetic domains, one of which freezes into a disordered state below $T_f \simeq 0.4$–$0.5\,K$ at a temperature relatively independent of the Yb concentration. The frozen spin moment of $\sim 0.1\mu_B$ is highly reduced from the high temperature free-ion value, and is independent of the Yb concentration.

The rare-earth bismuth platinum series of compounds (RBiPt) exhibits a variety of magnetic and transport phenomena, ranging from small-gap semiconducting behaviour in NdBiPt to metallic heavy-electron behaviour in YbBiPt [1]. The latter material exhibits an electronic specific heat C_p which is linear in temperature below 0.2 K with a slope γ corresponding to $8\,J/(K^2\,mol\,Yb)$, indicating the presence of extremely massive quasiparticles [2]. An abrupt change of $\partial\chi_{AC}/\partial T$ in the AC susceptibilty at $T_0 \simeq 0.4\,K$ in single crystals is characteristic of some sort of magnetic order below this temperature. The specific heat also peaks near $T_0 = 0.4\,K$. Muon spin relaxation (μSR) studies have been reported previously for crushed powders of YbBiPt [3]. The specific heat in powders is qualitatively the same as in single crystals but with a γ-value reduced by about 50% and a maximum at $T \simeq 0.5$–$0.6\,K$.

The μSR experiments in crushed powders could be interpreted [3] in terms of two types of magnetic domains: one type exhibiting disordered static magnetism below about 0.5 K, with a Yb moment much less than the free-ion value, and a second type which remains paramagnetic down to the lowest temperature measured (0.06 K). Rapid muon spin-lattice relaxation rates were also observed, characteristic of anomalously long Yb-spin correlation times. These observations are consistent with a highly frustrated Yb spin system which partially freezes below $T \simeq 0.5\,K$ (similar to but not identical with classical spin glasses) and raise the possibility that a high density of low-lying magnetic excitations contribute significantly to the large observed γ value. It was conjectured [3] that strain introduced by powdering could create the two types of magnetic domains, only one of which gives rise to the large value of γ.

To futher understand these issues, we have performed additional μSR experiments on crystalline materials. Initial zero-field results from these new experiments in $Yb_xY_{1-x}BiPt$ for $x = 1.0$ and 0.5 are reported here.

The μ^+SR experiments were carried out at the μSR facility of the Paul Scherrer Insitute, Villigen, Switzerland. The samples were prepared at Los Alamos by the flux-growth technique and several relatively large ($\leq 30\,mm^3$) pieces of crystalline material were glued to the cryostat cold finger. The temperature was regulated to better than 0.05 K. The measured zero-field relaxation functions $G_{ZF}(t)$ in the crystalline materials were found to be qualitatively similar to those seen

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Correspondence to: A. Amato, Institut für Mittelenergiephysik der ETH-Zürich, CH-5232 Villigen PSI, Switzerland.

previously in the powdered samples. As before, good fits were obtained for a sum of fast and slow components of the form

$$G_{ZF}(t) = A_f g_f(t) + A_s \exp(-\lambda_s t)\,, \qquad (1)$$

with the sum of the fast and slow amplitudes $A_f + A_s$ held constant as a function of temperature. The form of $g_f(t)$ changes from exponential $[g_f = \exp(-\lambda_f t)]$ at high temperature to Gaussian $[g_f = \exp(-\sigma_f^2 t^2)]$ for temperatures below $T_f \simeq 0.5$ K ($x = 1.0$) and $T_f \simeq 0.4$ K ($x = 0.5$) in the crystalline samples. This is shown in figs. 1 and 2 for $x = 1.0$ and 0.5, respectively, where the temperature dependence of σ_f, λ_f, λ_s, A_f and A_s is displayed for $T \leq 1.1$ K.

The temperature dependence of the Gaussian rate σ_f indicates an abrupt freezing of the Yb spins into a disordered ('random') state below about the same characteristic temperature T_0 observed for $x = 1.0$ in specific heat and AC susceptibility measurements. Similar behaviour was seen in crushed powders of YbBiPt. Note that the freezing temperature T_f is only slightly lower in the 50% Y sample. The extrapolated zero-temperature values for σ_f are $6.7 \pm 0.5\ \mu s^{-1}$ for $x = 1.0$ and $5.2 \pm 0.5\ \mu s^{-1}$ for $x = 0.5$, corresponding to rms local fields $\Delta H_L = \sigma_f/\gamma_\mu$ of about 77 and 60 Oe, respectively. Here γ_μ is the muon gyromagnetic ratio. The measurement in crushed powders of YbBiPt gave $\sigma_f \simeq 5\ \mu s^{-1}$ at zero temperature. The reduction in σ_f between $x = 1.0$ and $x = 0.5$ in the crystalline materials is consistent with that expected [4] for concentrated but uniformly diluted spin systems with no change in moment between $x = 1.0$ and $x = 0.5$ (i.e. $\sigma_f \propto \sqrt{x}$). Assuming dipolar Yb-muon coupling, these line widths correspond to a static Yb moment $\sim 0.1\mu_B$, about 3% of that deduced [2] from the susceptibility below 10 K.

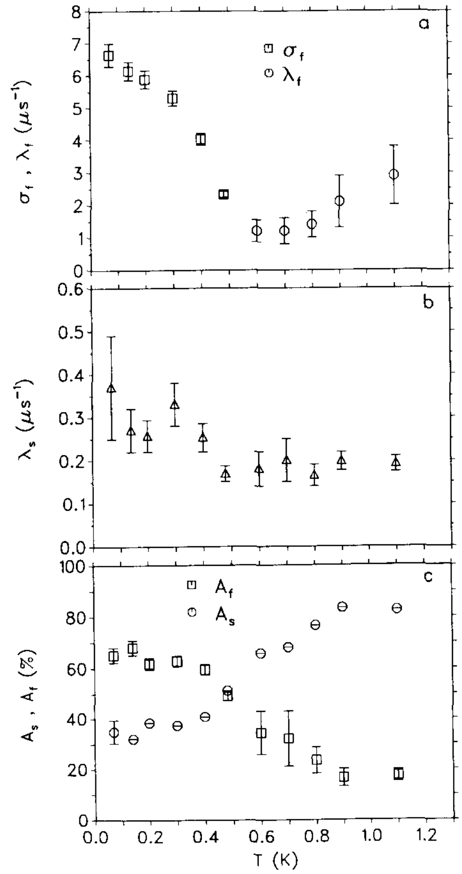

Fig. 1. Zero-field μSR data in crystalline YbBiPt: (a) temperature dependence of the exponential and Gaussian relaxation rate of the fast component; (b) temperature dependence of the exponential relaxation rate of the slow component; (c) temperature dependence of the amplitudes of the slow and fast components.

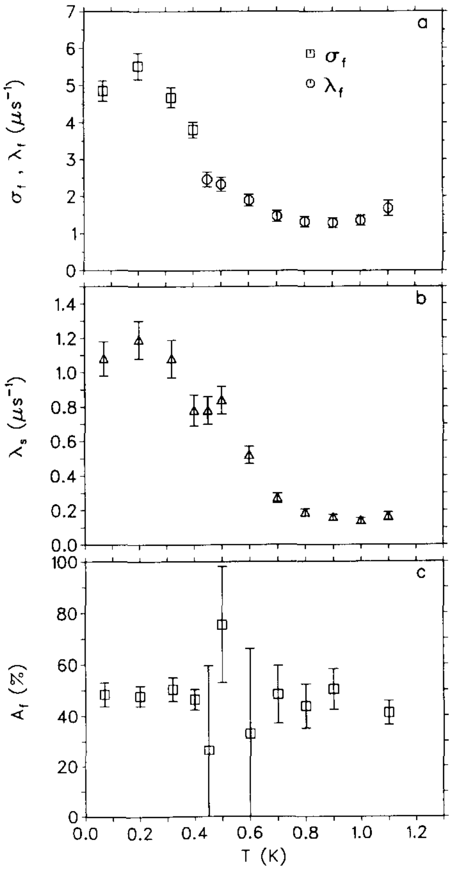

Fig. 2. Zero-field μSR data in crystalline $Yb_{0.5}Y_{0.5}BiPt$: (a) temperature dependence of the exponential and Gaussian relaxation rate of the fast component; (b) temperature dependence of the exponential relaxation rate of the slow component; (c) temperature dependence of the amplitude of the fast component. In the fit procedure to obtain the values of the relaxation rates, (a) and (b), the respective amplitudes were kept fixed at their average values.

The temperature dependences of the fast (A_f) and slow (A_s) component amplitudes are different for the $x = 1.0$ and $x = 0.5$ crystalline materials. As the temperature is lowered below 1.1 K, fig. 1(c) shows that A_f for $x = 1.0$ grows in magnitude, reaching $A_f \simeq 2/3$ at the lowest temperatures (where $A_f + A_s \equiv 1$). Qualitatively similar temperature dependent amplitudes were also observed for the YbBiPt crushed powders, where $A_f \simeq A_s$ was seen at the lowest temperatures and $A_f \ll A_s$ at 1.1 K. For the $x = 0.5$ crystalline material, however, $A_f \simeq A_s \simeq 1/2$ is observed for all temperatures between 0.08 and 1.1 K. Transverse field measurements indicate that only a single μ^+ stopping site is probable. Thus the fast and slow components defined by $G_{ZF}(t)$ most likely correspond to different magnetic domains. Therefore appreciable dilution of the Yb spins may produce isolated magnetic domains (of different character) which do not significantly change their size with temperature.

Relatively large zero-field spin lattice relaxation rates λ_f and λ_s (figs. 1 and 2) are observed above T_f in both the $x = 1.0$ and 0.5 crystalline materials, as well as the $x = 1.0$ powdered materials. (The expected Kubo–Toyabe relaxation rate from the Bi nuclear dipoles is $<0.1\ \mu s^{-1}$.) The measured values of λ_f and λ_s correspond to Yb-spin correlation times τ_c which are anomalously long [$\tau_c \simeq 10^3$–$10^4 (k_B T_f/\hbar)^{-1}$] in both kinds of domains. Here $(k_B T_f/\hbar)^{-1}$ is an order of magnitude estimate for τ_c in a conventional magnet.

In conclusion, μSR experiments on the crystalline YbBiPt give stong evidence for a highly frustrated spin system with anomalously long correlation times compared to the observed freezing temperatures. The frozen spin moment is significantly reduced from the free-ion value, as seen in other heavy electron systems. Dilution of Yb by 50% Y produces the expected reduction in the zero-temperature frozen spin linewidth $\sigma_f(0)$ but with little reduction in the spin-freezing temperature T_f. The existence of two different magnetic domains appears in both crystalline and crushed powder samples.

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