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Non-local superconductivity and the vortex-state properties of YNi_2B_2C

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Abstract

The magnetization M and heat capacity of clean, single crystal YNi_2B_2C superconductor have been studied with magnetic field $H \| c$-axis. The magnetization $M(H)$ deviates from conventional predictions, but is accurately described by recent non-local London theory, with well-behaved parameters. We show that the Ginzburg-Landau parameters κ_1 and κ_2 increase considerably as T decreases, similar to niobium, but with $\kappa(T_c) \approx 7$.

Keywords: Borocarbides; Magnetization; Non-local electrodynamics; Specific heat

The nickel–borocarbide superconductors are a rich and complex system of materials. These tetragonal materials have received great attention because of their remarkable properties, including the coexistence of magnetism and superconductivity and phase transitions in the vortex lattice (from simple hexagonal to rhombohedral to square symmetry), even for YNi_2B_2C that contains no magnetic rare earth ions [1,2]. This strange behavior of the vortex lattice has been explained in terms of non-local London theory [3] or generalized Ginzburg–Landau theory [4]. The non-local electrodynamics strongly affects the equilibrium magnetization M, which deviates significantly from conventional local London predictions, but agrees well [5] with recently generalized non-local London theory [6].

Magnetic studies were conducted in a SQUID magnetometer. The 17 mg single crystal, grown by a high-temperature flux method, was studied at temperatures T from far above T_c (14.5 K) to 2–3 K, in magnetic field $H \| c$-axis from zero to $H > H_{c2}$, the upper critical field. The in-field heat capacity was investigated to provide independent measures of $H_{c2}(T)$ and, by integration, the thermodynamic critical field $H_c(T)$. We obtain $H_c(0) = 2550$ G.

In general, the magnetization $M(H, T)$ exhibited little magnetic irreversibility, enabling an analysis of the crystal's equilibrium properties. The reversible M has been analyzed using standard London theory [7] near T_c and its non-local generalization [6] at lower temperatures. Nonlocal effects should be important when the BCS coherence length $\xi \approx 11$ nm is small compared with the electronic mean free path ℓ, as is the case here with $\ell \approx 30$ nm. Indeed, $M(H)$ deviates significantly from local London theory, but it is well-described by non-local London theory, with well-behaved parameters; e.g., $1/\lambda^2(T) \sim (1 - t^2)$ with $\lambda(0) = 89$ nm. A further consequence of "cleanliness" and a large ℓ is that the Ginzburg–Landau parameters κ_1 and κ_2 should vary significantly with temperature. Variations in these quantities have been largely ignored in studies to date on borocarbide superconductors.

According to Maki theory [8], extensions beyond the constant-κ approximation are needed for clean materials at lower temperatures. There one has $H_{c2} = \sqrt{2}\kappa_1 H_c$ and $4\pi(\mathrm{d}M/\mathrm{d}H)_{\mathrm{Hc2}} = 1/\beta_A[(2\kappa_2^2 - 1)]$. Experimentally,

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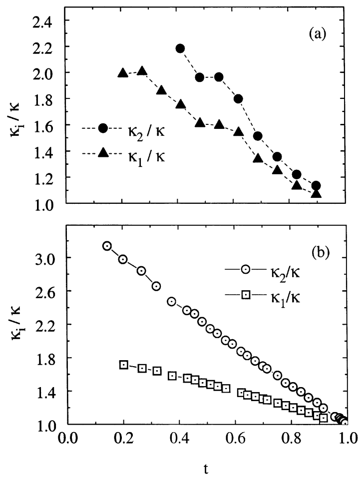

Fig. 1. (a) The Ginzburg–Landau parameters κ_1 and κ_2 for YNi_2B_2C with field $H \| c$-axis versus reduced temperature $t = T/T_c$; $\kappa \approx 7$ at T_c. (b) For comparison, the same parameters measured in single crystal Nb, with $H \| (001)$; $\kappa = 0.773$ at T_c.

we have H_c and H_{c2} from both magnetization and heat capacity measurements. Also, we have (background corrected) $M(H)$ curves extending into the normal state, which provide values for κ_2. The results for κ_1 and κ_2 for the single crystal of YNi_2B_2C are shown in Fig. 1 as a function of reduced temperature $t = T/T_c$. Each κ_i is normalized by the (common) value $\kappa = 7$ at T_c. The deduced values of κ_i increase significantly as T decreases. For comparison, corresponding results are shown for a high purity, single crystal of Nb [9]. The behavior is remarkably similar for the low-κ Nb and intermediate-κ material YNi_2B_2C.

To conclude, the temperature dependence of κ_1 and κ_2 and the non-local London magnetization both point to significant effects of non-local electrodynamics in the YNi_2B_2C, consistent with its long electronic mean free path.

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