Magnetic Field Dependence of the Low-temperature Specific Heat of $MgCNi_3$

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Abstract

The specific heat of a superconductor carries crucial signature of its order parameter. The newly discovered superconductor $MgCNi_3$ is predicted to be unstable to ferromagnetism, and the symmetry of its order parameter symmetry is of current interest. To shed light on this issue, we have measured the low-temperature specific heat of $MgCNi_3$ in H. Careful analysis of the data suggests that $\gamma(H) \propto H$. Together with other physical properties, the results imply that $MgCNi_3$ is a moderate-coupling BCS superconductor.

Key words: $MgCNi_3$; specific heat; order parameter; The mixed state

The newly discovered superconductivity in $MgCNi_3$ has been a surprise [1]. $MgCNi_3$ can be regarded as fcc Ni with only one quarter of Ni replaced by Mg and with C sitting on the octahedral sites. With the structure so similar to that of ferromagnetic Ni, there has been theoretical speculation that $MgCNi_3$ is with strong ferromagnetic fluctuations [2]. To be compatible with the magnetic fluctuations, there is a possibility that $MgCNi_3$ has p-wave order parameter. The magnetic field dependence of $\gamma(H)$ is sensitive to the symmetry of the order parameter [3]. For a gapped superconductor, $\gamma(H)$ is expected to be proportional to H where γ is the linear coefficient of C with respect to T. For nodal superconductivity, $\gamma(H) \propto H^{1/2}$ is predicted. It is therefore of interest to study C of $MgCNi_3$ in detail. In this paper, the magnetic field dependence of C is analyzed.

The MgCNi3 sample was prepared based on the procedure described in [1]. The x-ray diffraction pattern revealed the nearly single phase of $MgCNi_3$ structure. It is well known that T_c significantly depends on the real carbon content in the nominal MgCNi3 [1]. Magnetization, specific heat, and resistivity measurements all showed a superconducting onset at about 7 K in the present sample. The resistivity transition width is less than 0.5 K, while thermodynamic T_c determined from $C(T)$ is 6.4 K. $C(T)$ was measured using a ^{3}He thermal relaxation calorimeter from 0.6 to 10 K with magnetic fields H up to 8 T.

The results of the specific heat measurements were reported in [4] in detail. $\Delta C/\gamma_n T_c$=1.97 is estimated from the anomaly at T_c. This indicates a moderate-coupling superconductivity within the BCS context. Fig. 1 shows C/T vs. T^2 at low T in magnetic fields. To figure out $\gamma(H)$, the data was extrapolated to T=0 for $H \geq$4T as indicated by the straight lines in Fig. 1. The low field data suffer contamination from the paramagnetic contribution of the impurities, and $\gamma(H)$ can only be obtained through the attempts of the fitting. For the approximation, consider $C(T,H) \simeq C(T,H=0) + \gamma(H)T + C_m(T,H)$, where C_m is the paramagnetic contribution and assumed to be in the Schottky form. If we take the zero-field data between 2.5 and 4.5 K as $C(T,H=0)$(to avoid the magnetic contribution at

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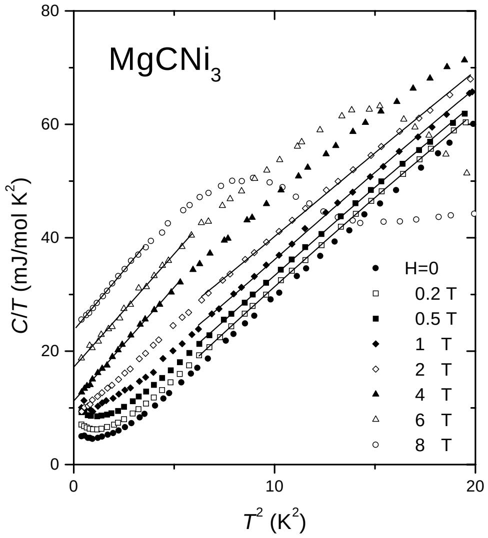

Fig. 1. $C(T, H)/T$ vs. T^2 of $MgCNi_3$ for H=0 to 8 T. The solid lines are either to extrapolate γ in high fields or to represent the fits mentioned in the text for low field data .

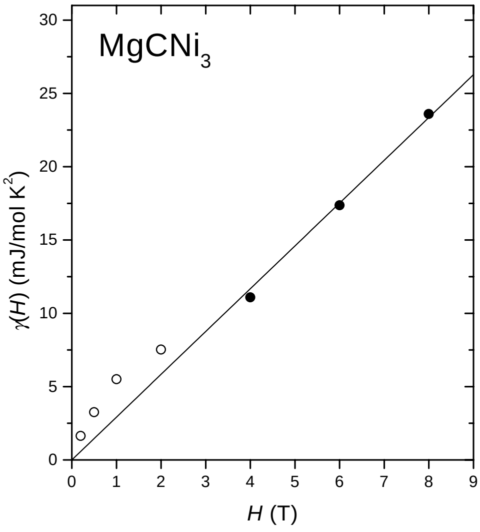

Fig. 2. $\gamma(H)$ obtained from either extrapolation (high field) or fitting (low field).

low temperatures), $\gamma(H)$ can be estimated by fitting $C(T, H)$ in this temperature range. The resulting $\gamma(H)$ with $H \leq 2$ T is shown in Fig. 2 together with the high field γ obtained as mentioned above.

Linearity of γ can be clearly seen in high H from Fig. 2, while a nonlinear $\gamma(H)$ at low H is likely as suggested by the fits. $\gamma(H)$ tends to revert to be linear at high H as suggested in Fig. 2. The nonlinearity in low H can be attributed to the flux line interactions [5]. The linear γ, together with the full superconducting gap and other evidences reported in [4], suggests a s-wave order parameter in $MgCNi_3$. It is noted that other form of C_m would lead to slightly different results for low field γ and could bring γ more close to the linearity. Fitting with other forms of C_m will be reported elsewhere.

Acknowledgements

This work was supported by National Science Council, Taiwan, Republic of China under contract Nos. NSC90-2112-M-009-025 and NSC90-2112-M-110-012.

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