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Various analyses of specific heat for the order parameter of superconductor $Na_{0.35}coO_2 \cdot 1.3H_2O$

C.P. Sun[a], J.-Y. Lin[b], Y.C. Kang[a], C.L. Huang[a], K. Takada[c], T. Sasaki[c], H. Sakurai[d], E. Takayama-Muromachi[d], H.D. Yang[a,*]

[a]*Department of Physics, National Sun Yat Sen University, Kaohsiung 804, Taiwan, Republic of China*
[b]*Institute of Physics, National Chiao Tung University, Hsinchu 300, Taiwan, Republic of China*
[c]*Soft Chemistry Research Group, Advanced Materials Laboratory, National Institute for Materials Science, 1-1 Namiki, Tsukuba, Ibaraki 305-0044, Japan*
[d]*Superconducting Materials Center, National Institute for Materials Science, 1-1 Namiki, Tsukuba, Ibaraki 305-0044, Japan*

Abstract

Low-temperature specific-heat data $C(T)$ of two $Na_{0.35}CoO_2 \cdot 1.3H_2O$ samples (I and II) with temperature T down to 0.6 K without and with magnetic field of 8 T are presented. The normal-state linear coefficient of specific heat γ_n, Debye temperature Θ_D, superconducting transition temperature T_c, specific heat jump at T_c, $\Delta C/\gamma_{ns}T_c$, and superconducting volume of fraction (SVF) are 14.89 mJ/mol K^2, 503, 4.7 K, 1.96, and 26.6% for sample I and 13.94 mJ/mol K^2, 362, 4.5 K, 1.45, and 47.4% for sample II, respectively. Because the superconducting properties may depend on the water content of sample, it is found that the better quality (higher SVF) of sample, the nodal order parameter is better than BCS isotropic s-wave model in describing the gap function of this interesting compound $Na_{0.35}CoO_2 \cdot 1.3H_2O$.

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Keywords: Sodium cobalt oxides; Superconductivity; Specific heat

1. Introduction

It has attracted lots of interests on sodium cobalt oxide, both in unhydrated and hydrated compounds, due to its unusual physical properties including large thermoelectric power and the occurrence of superconductivity [1]. In this material, CoO_2 forms 2D triangular lattice and is considered exhibiting a possible different mechanism of superconductivity from high T_c cuprates in which the CuO_2 forms square lattice. In our recent paper, we reported the nodal superconductivity in one specific sample $Na_{0.35}CoO_2$ $1.3H_2O$. [2]. However, due to the instability of water content in the sample, the superconducting volume of fraction (SVF) changes sample by sample. Here we present two sets of specific heat data measured on samples from two different batches for comparison to explore the possible sample dependence of superconducting properties.

2. Results and discussion

The sample preparation was described in detail elsewhere [1]. The difference of preparation between two samples was the amount of bromine (Br_2) used in soft-chemical processes with chemical oxidation. Heat-pulse thermal relaxation calorimetry [3] was used to take low-temperature specific-heat data down to 0.6 K without and with magnetic field up to 8 T. In Fig. 1, the solid line is the normal state fitting deduced from the 8 T data by using $C_n = \gamma_n + C_{lattice}(T)$, where $\gamma_n T$ is the electronic term due to free charge carriers and $C_{lattice}(T) = \beta T^3 + \alpha T^5$ represents the phonon contribution. It is noted that the C/T is not zero as T extrapolates to zero in Fig. 1. This indicates that there is a portion of sample not going to superconducting state below T_c. The obtained γ_n, Θ_D, T_c, $\Delta C/\gamma_{ns}T_c$, and

*Corresponding author. Tel.: +886 7 523 3732; fax: 886 7 525 3709.
E-mail address: yang@mail.phys.nsysu.edu.tw (H.D. Yang).

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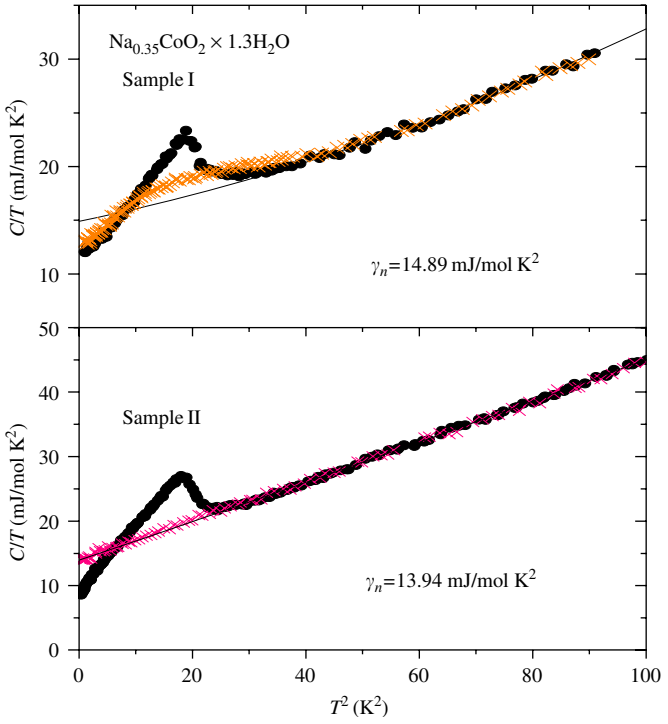

Fig. 1. The sample dependence of specific heat without and with magnetic field of 8 T are presented. The solid line is the fitting line of normal state.

Table 1
The superconducting parameters of two samples

	γ_n (mJ/mol K^2)	Θ_D (K)	T_c (K)	$\Delta C/\gamma_{ns}T_c$	SVF (%)
sample I	14.89	503	4.7	1.96	26.6
sample II	13.94	362	4.5	1.45	47.4

estimated SVF for two samples are listed in Table 1, where SVF $= \gamma_{ns}/\gamma_n$, γ_{ns} is referred to the part of electrons going to superconducting state and γ_n is referred to normal-state electrons.

Two possible models, conventional isotropic s-wave and line node models are considered to fit the electronic specific-heat data in superconducting state (C_{es}) (Fig. 2). The fitting equation is

$$C_{es} = 2N(0)\beta k \frac{1}{2\pi}\int_0^{2\pi} d\phi \int_{-\hbar\omega_D}^{\hbar\omega_D} -\frac{\partial f}{\partial E}\left(E^2 + \frac{1}{2}\beta\frac{d\Delta^2}{d\beta}\right) d\varepsilon,$$

where $N(0)$ is the density of states at Fermi surface, $\beta = 1/kT$, $E = (\varepsilon^2 + \Delta^2)^{1/2}$, $f = (1 + e^{\beta E})^{-1}$, $\Delta = \Delta_0$ the superconducting energy gap for an isotropic s-wave, $\Delta = \Delta_0 \cos\phi$ for a line nodes ($n = 2$ is taken corresponding to d-wave). Though it shows a equally good fit in sample I (with lower SVF) within the studied temperature region, it is obvious that the line node is better than the BCS isotropic *s*-wave in describing the data in sample II (with higher SVF). Our results also support the early reports of NQR and NMR [4,5] and μSR measurements [6]. which the order parameter was interpreted to show a line node.

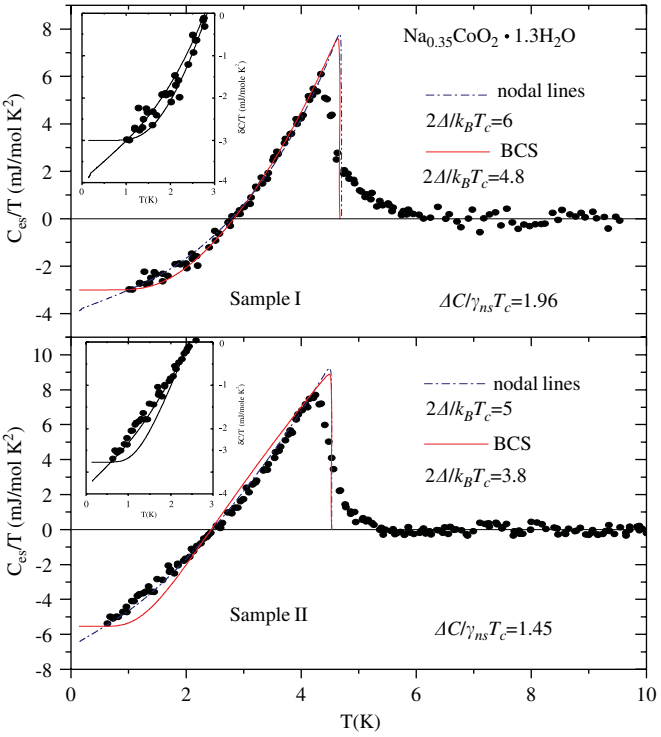

Fig. 2. The single gap and line node are performed on the C_{es} of two samples. The solid and dash lines are represented for the fitting of an isotropic s-wave and a nodal-line models.

3. Conclusion

In conclusion, though the superconducting parameters such as T_c, γ_n, Θ_D, $\Delta C/\gamma_{ns}$, T_c, and SVF depend on samples (may be the water content), the gap function of better sample can be better described by a line node than a BCS isotropic s-wave pairing.

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