UC Irvine

UC Irvine Previously Published Works

Title

Magnetic susceptibility of Nb₃Sb

Permalink

<https://escholarship.org/uc/item/4jb4d15m>

Journal

Physics Letters A, 73(4)

ISSN

0375-9601

Authors

Webb, GW

Fisk, Z

Johnston, DC

Publication Date

1979-10-01

DOI

10.1016/0375-9601(79)90556-5

Copyright Information

This work is made available under the terms of a Creative Commons Attribution License, available at <https://creativecommons.org/licenses/by/4.0/>

Peer reviewed

MAGNETIC SUSCEPTIBILITY OF Nb₃Sb[☆]

G.W. WEBB, Z. FISK and D.C. JOHNSTON¹

*Institute for Pure and Applied Physical Sciences, University of California, San Diego,
La Jolla, CA 92093, USA*

Received 20 June 1979

We have measured the magnetic susceptibility of Nb₃Sb, a low density of states A-15 compound. The measurements were performed on a large single crystal over the temperature range 4 to 294 K. The susceptibility is found to be small with a negative temperature derivative over most of this interval, the total variation being 7%.

The A-15 structure class of materials exhibits the highest known superconducting transition temperatures (T_c) [1]. For this reason, these materials are the subject of much current interest. In addition to their high T_c 's, this class of materials exhibits unusual normal state properties such as uncommon temperature dependences to their resistivities at low and high temperatures [2–8], to their elastic moduli [10,11] and to their low temperature heat capacities [9,12]. It is widely felt that the underlying physical features which are responsible for these unusual normal state properties (and others) are also responsible for the occurrence of high T_c .

In particular, the magnitude and temperature dependence of the electrical resistivity of A-15 structure materials has received much recent attention. At room temperature their resistivities are large, of order $70\ \mu\Omega$ cm, and do not display the "usual" linear in T dependence. Their less than linear T dependence has led to the suggestion that the resistivity is approaching a saturation or Mott limit, corresponding to an electron mean free path of order an interatomic spacing [8]. The large magnitude of the room temperature resistivity is perhaps to be expected for materials such as the high T_c A-15 structure materials which have both high densities of states at the Fermi surface and large elec-

tron phonon interaction parameter (λ). Several analyses [4,6,7,9,13] differing in details, postulate that such high resistivities are due to strong interband scattering from a single broad conduction band into an overlying high density of states "d" band.

Nb₃Sb is known to have a low $T_c = 0.2$ K, a low density of states at the Fermi level and a small electron phonon coupling constant, λ [12]. If comparison is made below room temperature, e.g. 50 K, Nb₃Sb is indeed found to have a much smaller resistivity than the high T_c members of this class, as might be expected [8,9]. However, at room temperature and above the resistivity of Nb₃Sb has risen to above $70\ \mu\Omega$ cm, a value comparable to the high T_c materials and also appears to be saturating with increasing temperature [8,9].

Several explanations [7,13] for the observations on Nb₃Sb suggest that there is a high density of states "d" band like feature within a maximum phonon energy of the Fermi energy which becomes energetically accessible^{‡1} for scattering at room temperature and above. This interpretation would receive strong confirmation if the Pauli part of the magnetic susceptibility, χ , were found to have a positive temperature derivative with a magnitude at room temperature and

[☆] Research supported by the National Science Foundation.

¹ Present address: Corporate Research Laboratories, Exxon Research and Engineering Co., Linden, NJ 07036, USA.

^{‡1} To be consistent it should be noted that the electron phonon interaction averages over structure in the density of states within a maximum phonon energy of the Fermi level [14].

above comparable to that of higher T_c A-15 structure compounds.

To investigate the temperature dependence of χ in Nb_3Sb a large single crystal in the shape of an octahedron with a mass of ~ 1 g was selected. It was grown by closed tube vapor transport with iodine as a transporting agent. The purity of the starting material was 4–9's for the Sb and is estimated to be 3–9's for the Nb.

The susceptibility measurements were performed on a Faraday magnetometer in a field of 8 kG. The magnetization of the sample was measured as a function of field up to 10 kG at the temperatures 290 K and 4 K. The magnetization data are linear in field showing that ferromagnetic impurities are negligible. The measured gram susceptibility, χ , is shown in fig. 1.

The susceptibility has the value 0.835×10^{-6} emu/g at 294 K, a value at the lower end of what has

been measured for Nb based A-15 compounds [11, 15–18]. With decreasing temperature χ rises by 7% at the lowest temperatures. Some of these data are given in table 1. As is usually done, the measured susceptibility can be expressed as

$$\chi_{\text{meas}} = \chi_{\text{spin}} + \chi_{\text{orb}} + \chi_{\text{dia}},$$

a sum of spin, orbital and diamagnetic core contributions, respectively [15–19]. For 4d elements a value near -17×10^{-6} emu/g atom is often used [18] for χ_{dia} . Making this correction to χ_{meas} we arrive at entry III of table 1.

It is instructive to compare $\chi_{\text{meas}}(0 \text{ K}) - \chi_{\text{dia}}$ with the calculated "bare" Pauli spin susceptibility of a non-interacting electron gas. The bare density of states for Nb_3Sn and Nb_3Sb has been extracted [12] from low temperature heat capacity measurements, allowing the bare Pauli terms to be calculated as shown in entry IV of table 1. We note that the ratio of the calculated Pauli terms for Nb_3Sn to Nb_3Sb is 6 while the ratio of $\chi_{\text{spin}} + \chi_{\text{orb}}$ is 3. This difference could be due to χ_{orb} being a significant fraction of the total $\chi^{\pm 2}$ and/or that the Stoner enhancement of χ_{spin} is larger for Nb_3Sb than for Nb_3Sn . Klein et al. [20] have fit the susceptibility of Nb_3Sn using $\chi_{\text{orb}} \approx 0.99 \times 10^{-6}$ emu/g ($= 98.4 \times 10^{-4}$ emu/g atom), a signif-

^{±2} We do not have enough information to include a correction term for the Landau diamagnetism of the conduction electrons. However, if included, it would have the effect of increasing the estimated χ_{orb} .

Table 1

All susceptibilities are expressed in units of 10^{-6} emu/g atom (i.e. per Avogadro's number of atoms). For comparison the room temperature susceptibility of Nb is 204×10^{-6} emu/g atom [19].

		$\text{Nb}_3\text{Sb}^{\text{a}}$	Nb_3Sn
I	$\chi_{\text{meas}}(300 \text{ K})$	83.1 ^b	202 ^c
II	$\chi_{\text{meas}}(0 \text{ K})^{\text{d}}$	89.1	266 ^{c,d}
III	$\chi(0 \text{ K})_{\text{meas}} - \chi_{\text{dia}}^{\text{e}}$ $= \chi_{\text{spin}} + \chi_{\text{orb}}^{\text{f}}$	106.1	283
IV	$\chi_{\text{Pauli spin}}^{\text{f}}$	12.9	77.3

a) This work. b) Extrapolated from 294 K.

c) Data from Rehwal et al. [11].

d) Extrapolated cubic state value.

e) $\chi_{\text{dia}} \approx -17 \times 10^{-6}$ emu/g atom from Bardos et al. [18].

f) Using bare densities of states from Knapp et al. [12].

Fig. 1. The measured magnetic susceptibility in units of 10^{-6} emu/g for Nb_3Sb , present investigation, and Nb_3Sn from Rehwal et al. [11]. The dashed line is the cubic state extrapolation to low temperature for Nb_3Sn from ref. [11]. Note that both materials show a negative temperature derivative over most of the temperature range shown. For comparison the room temperature susceptibility of Nb is 2.2×10^{-6} emu/g with a slight negative temperature deviative [19].

icant fraction of the measured χ (a large Stoner enhancement of χ_{spin} was inferred also).

It is seen in fig. 1 that $d\chi/dT$ is negative in cubic Nb_3Sn . This fact has been interpreted as arising from the Fermi level moving into a region of lower density of states with increasing temperature, due to the proximity of either a step in the density of states near the Fermi level or a density of states peak [4]. Recent calculations of χ_{spin} for Nb_3Sn based on band structure calculations have confirmed that the temperature dependence indeed is due, at least in part to Fermi level motion [20,21]. In Nb_3Sb , $d\chi/dT$ is much smaller in magnitude but of the same sign as Nb_3Sn possibly indicating some Fermi level motion also. However, there is no evidence in the χ data of a positive $d\chi/dT$ with increasing temperature which would indicate a thermal population of a nearby d state. Since high-precision band-structure data are available for both materials [20,21], it seems that a calculation of χ_{orb} for Nb_3Sn both χ_{spin} and χ_{orb} for Nb_3Sb would be possible and timely.

In conclusion, our magnetic susceptibility data do not support an explanation for the magnitude and temperature dependence of the resistivity of Nb_3Sb based on a high density of states feature near the Fermi level. Other explanations are still tenable; one such possibility is that intersheet scattering from a complex Fermi surface gives a high magnitude to the resistivity which leads to a saturating resistivity at high temperatures.

References

- [1] B.W. Roberts, J. Phys. Chem. Ref. Data 5 (1976) 581.
- [2] M.P. Sarachik, G.E. Smith and J.H. Wernick, Can. J. Phys. 41 (1963) 1542.
- [3] D.W. Woodard and G.D. Cody, Phys. Rev. 136 (1964) A166.
- [4] R.W. Cohen, G.D. Cody and J.J. Halloran, Phys. Rev. Lett. 19 (1967) 840; also R.W. Cohen, Conf. Proc. on Superconductivity in d- and f-band metals (Rochester, NY, 1971).
- [5] A. Marchenko, Sov. Phys. Solid State 15 (1973) 1261.
- [6] P.B. Allen, J.C.K. Hui, W.E. Pickett, C.M. Varma and Z. Fisk, Solid State Commun. 18 (1976) 1157.
- [7] S.J. Williamson and M. Milewits, Rochester Conf. on Superconductivity in d- and f-band metals (Rochester, NY, 1976) p. 551.
- [8] Z. Fisk and G.W. Webb, Phys. Rev. Lett. 36 (1976) 1084.
- [9] G.W. Webb, Z. Fisk, J.J. Engelhardt and S.D. Bader, Phys. Rev. B15 (1977) 2624.
- [10] L.R. Testardi, R.R. Soden, E.S. Greiner, J.H. Wernick and V.G. Chirba, Phys. Rev. 154 (1967) 399.
- [11] W. Rehwald, M. Rayl, R.W. Cohen and G.D. Cody, Phys. Rev. B6 (1972) 363.
- [12] G.S. Knapp, S.D. Bader and Z. Fisk, Phys. Rev. B13 (1976) 3783.
- [13] S.D. Bader and F.Y. Fradin, Rochester Conf. on Superconductivity in d- and f-band metals (Rochester, NY, 1976) p. 567.
- [14] S.J. Nettle and H. Thomas, Solid State Commun. 21 (1977) 683.
- [15] A.M. Clogston, A.C. Gossard, V. Jaccarino and Y. Yafet, Rev. Mod. Phys. 36 (1964) 170.
- [16] R.H. Willens et al., Solid State Commun. 7 (1969) 837; N. Ye. Alekseyevski, N.V. Ageyev and V.F. Shamray, Fiz. Met. Metalloved. 43 (1977) 38.
- [17] M. Bernasson, P. Descouts, R. Flükiger and A. Treyvaud, Solid State Commun. 8 (1970) 837.
- [18] D.I. Bardos, R.M. Waterstrat, T.J. Rowland and J.B. Darby Jr., J. Low Temp. Phys. 3 (1970) 509.
- [19] C.F. Kriessman, Rev. Mod. Phys. 25 (1953) 122.
- [20] B.M. Klein, L.I. Boyer and D.A. Papaconstantopoulos, Phys. Rev. Lett. 42 (1979) 530.
- [21] A.T. van Kessel, H.W. Myron and F.M. Mueller, Phys. Rev. Lett. 41 (1978) 181.