

CONF-970814--15

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W-7405-ENG-82

CHAPTER 5. INELASTIC NEUTRON STUDIES OF THE LOW ENERGY PHONON EXCITATIONS IN THE $RE\text{Ni}_2\text{B}_2\text{C}$ SUPERCONDUCTORS (RE=Lu, Y, Ho, Er)

A paper presented at ICNS

International Conference
on Neutron Scattering

M. Bullock, C. Stassis, J. Zarestky, A. Goldman, P. Canfield

Ames Laboratory and Department of Physics, Iowa State
University, Ames, IA 50011

G. Shirane and S. Shapiro

Brookhaven National Laboratory, Upton, NY 11973

Abstract

We studied the low-energy phonon excitations for wavevectors close to the Fermi surface nesting vector $\vec{\xi}_m \approx 0.55\vec{a}$. We find that above T_c the frequencies of the $\Delta_4[\zeta 00]$ lowest-lying optical and acoustic phonon modes decrease with decreasing temperature, for $\vec{\xi}$ close to $\vec{\xi}_m$, and there is a shift of intensity from the upper to the lower mode, an effect characteristic of coupled modes. From approximately 120K down to temperatures in the vicinity of T_c , only a single unresolved peak is observed. Below T_c the phonon spectra of the Y and Lu compounds change dramatically: they consist of

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a sharp peak at approximately 4.5 meV with a weak shoulder at the higher energy side. No such sharp peak was observed below T_c in the Ho and Er compounds.

Introduction

Many of the body-centered tetragonal $RENi_2B_2C$ compounds are superconductors with relatively high superconducting transition temperatures ($T_c=16.5$, 15.5, 10.5, and 8.5 for the Lu, Y, Er, and Ho compounds) and in some cases ($RE = Tm$, Ho, Er, and Dy) superconductivity co-exists with magnetic order.⁽¹⁾ Of particular interest, for the present study, is that the frequencies of the lowest lying phonon modes near the nesting vector $\vec{\xi}_m$ decrease with decreasing temperature,^(2,3) and a dramatic change in the phonon spectra of both Y⁽³⁾ and Lu⁽⁴⁾ compounds was observed below T_c . In this report we present a brief summary of the results obtained in a systematic study of the low-lying phonon excitations of the Lu, Y, Ho, and Er compounds.

The branches of interest are the acoustic and lowest lying optical branch in the $[\xi 00]$ direction, both belonging to the Δ_4 representation. The dispersion of these branches at room temperature, for the Y compound, is shown in Fig.

5.1. The phonon energies for the Lu, Ho, and Er are, of course, lower than in the Y compound. At room temperature

two peaks are observed for ξ up to approximately 0.45, but these peaks are not easily resolved for ξ in the vicinity of 0.5 (See Fig. 5.2).

As the temperature decreases, the energies of the modes in the vicinity of ξ_m decrease and there is transfer of intensity from the optic to the acoustic mode. For temperatures lower than approximately 120K, the two modes cannot be resolved and only a broad feature is observed. This is illustrated for the Lu compound in Fig. 5.2. In the Y compound, it was necessary to perform measurements at temperatures higher than room temperature in order to see clearly this mode interaction. As in the case of ferroelectric materials, the temperature dependence of the anticrossing behavior of the modes observed in the present experiments can be formulated as a problem of mode coupling via anharmonic forces^[5].

At temperatures below approximately 120K, and down to the vicinity of T_c , the Δ_4 optical and acoustic modes close to ξ_m cannot be resolved and only a relatively broad feature is observed (see third panel of Fig. 5.2 and insert in the first panel of Fig. 5.3). Below T_c the phonon spectra for the Lu and Y change dramatically. They consist of a sharp peak at approximately 4.5 meV with a weak shoulder at the higher energy side. The width and position of this sharp peak remain practically unchanged below T_c , its intensity decreases

with increasing temperature, and it is practically indistinguishable from the background at temperatures close to T_c (see insert in the second panel of Fig. 5.3). From a study of the energies of the sharp peak and the broad shoulder as a function of ξ and ζ (along the $[00\zeta]$ direction), we concluded ^[5] that the sharp peak must be associated with the acoustic mode and the barely visible shoulder with the optical mode. No such sharp peak was observed in the Ho (see panel 3 of Fig. 5.3) and Er compounds at low temperatures. It should be pointed out, however, that the detailed study of the low lying phonon excitations in these magnetic superconductors is hindered by the presence of peaks corresponding to crystal electric field (CEF) levels (at approximately 10 meV in Ho and 5 meV in Er).

The experimental results show that the dramatic change in the phonon spectra of the Lu and Y compounds below T_c must be related to the abrupt change in the polarizability of the superconducting electrons at $\omega=2\Delta$. Actually, recent calculations^[6,7] yield phonon spectra almost identical to those observed in the present experiments. It should be pointed out, however, that in both approaches the theoretically predicted BCS temperature dependence of the sharp peak does not agree very well with the present experimental results.

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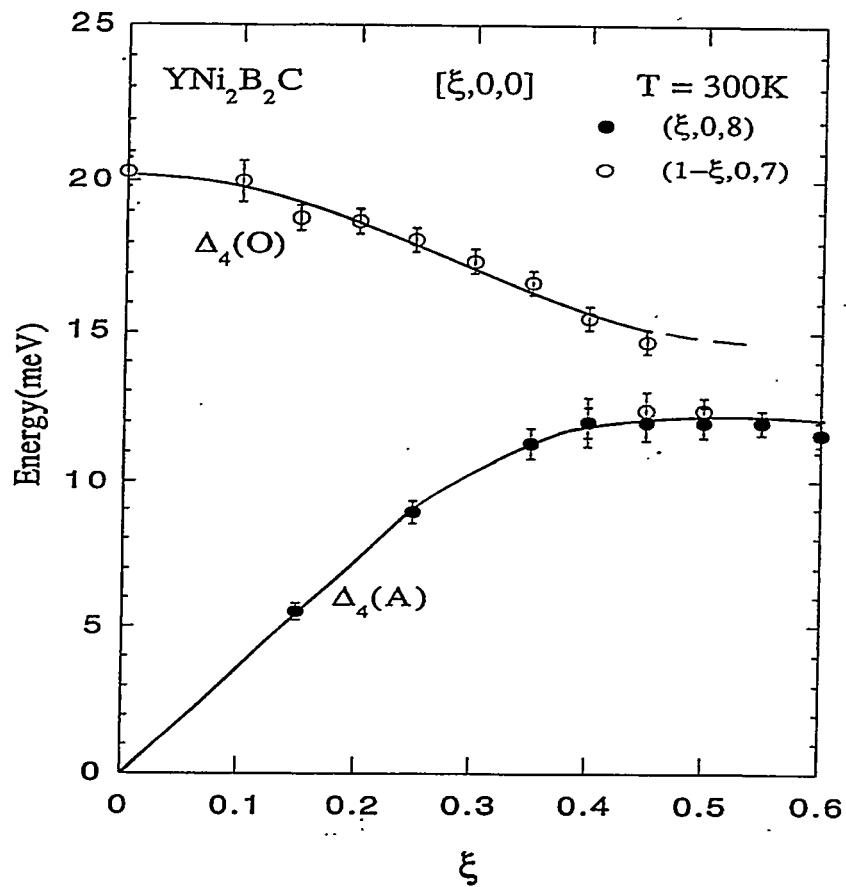


Fig. 5.1 Room temperature phonon dispersion of the Δ_4 acoustic (A) and optic (O) branches of $\text{YNi}_2\text{B}_2\text{C}$. For $\zeta > \xi_m$ the intensity of the optical modes is very weak and this is indicated by a dotted line. The lines are used as a guide to the eye.

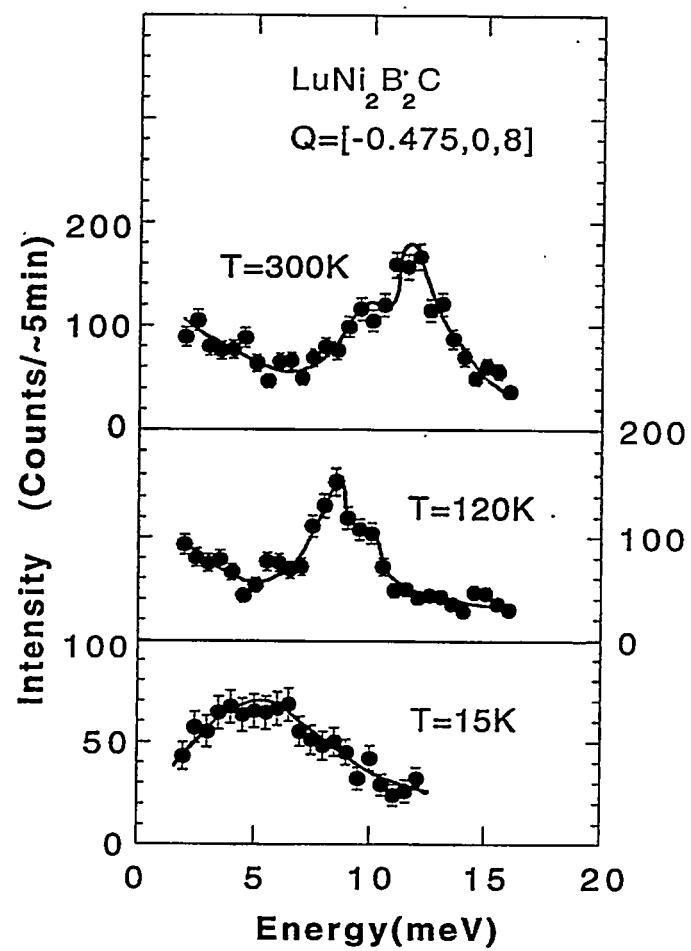


Fig. 5.2 Temperature dependence of the phonon spectra in the vicinity of ξ_m in the Lu compound, the lines are used as a guide to the eye.

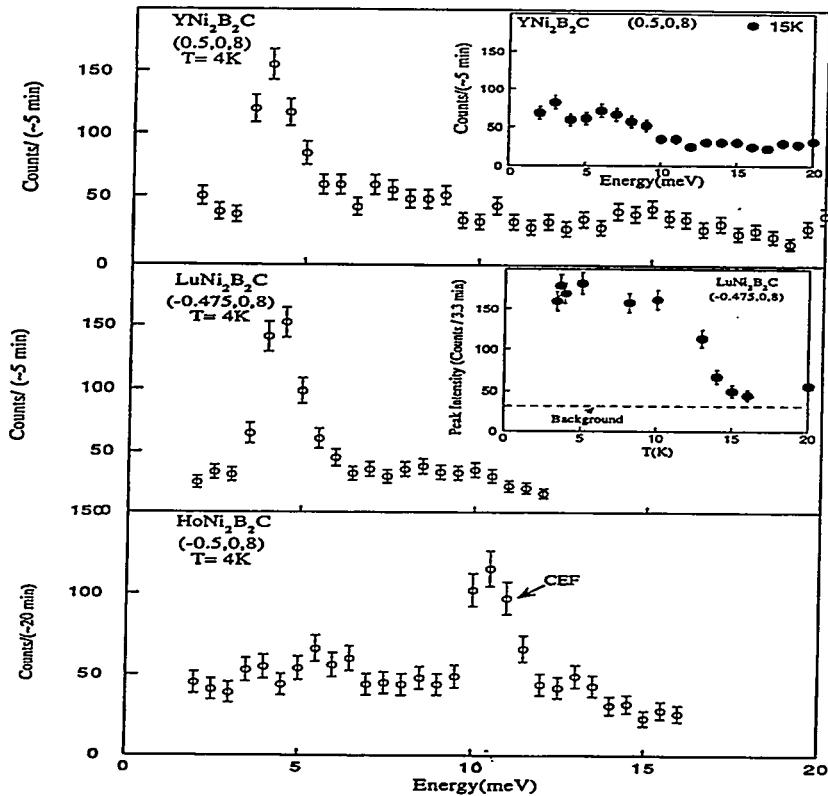


Fig. 5.3 Phonon profiles obtained below T_c for the Y, Lu and Ho compounds. Upper insert: typical phonon profile in the vicinity of T_c . Lower insert: temperature dependence of the intensity of the sharp peak (see text).