Measurement of an anisotropic superconducting gap parameter resolved to a single Fermi surface sheet: YNi_2B_2C

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Abstract

We have used the de Haas–van Alphen technique in the normal and superconducting states of YNi_2B_2C to measure the (angularly resolved) orbitally averaged superconducting gap parameter. The results show that the gap parameter is highly anisotropic. This is the first time that superconducting gap anisotropies have been explored and resolved to individual sheets of the Fermi surface. In addition we have observed for the first time an excess damping due to screening by vortex motion in the peak effect region.

Key words: superconductivity; de Haas–van Alphen effect ; gap anisotropy ; YNi_2B_2C

The question of whether YNi_2B_2C exhibits s- or d-wave symmetry of the superconducting gap parameter is presently hotly debated. See [1], [2] for instance, for recent views and references.

We have used the de Haas–van Alphen (dHvA) effect to explore the superconducting state of YNi_2B_2C. See [3], [4], [5] and [6] for previous work. See [7], [8] for experiment and theory.

The de Haas–van Alphen measurements presented here were performed using a rotating sample platform at temperatures down to 280 mK in a superconducting magnet providing magnetic fields up to 18 T. The field modulation technique was used with modulation field parameters of 0 to 0.05 T at 5 to 500 Hz. Standard amplification and lock-in techniques were implemented. Temperatures were measured using calibrated Cernox and RuO_2 thermometers corrected for the high magnetic field. Signal pickup was via balanced ≈ 3000 turn Cu pick up coils.

The samples were supplied by K.Krug and K.Winzer of the Universität Göttingen.

Raw dHvA data for the magnetic field along $< 001 >$ shows at least seven dHvA frequencies plus harmonics in the normal state. Two of these, at 502 T and 6912 T survive into the superconducting state. After determining and dividing out all of the normal state parameters we observe the usual reduction in amplitude of the dHvA signal in the superconducting state. Figure 1 shows plots of the superconducting damping factor, Rs, for the 6912 T frequency. It is seen that there is a strong dependence on the modulation field amplitude just below Hc2. We believe this is due to screening of the dHvA signal by flux flow effects in the peak effect region and must be taken account of in future experiments. The signal becomes insensitive again to changes of the modulation field amplitude at lower fields, i.e. it recovers the expected Bessel function dependence.

Figure 2 shows standard Dingle plots of the dHvA data for several angles of the crystal away from $< 001 >$ towards $< 110 >$ for the 502 T frequency. The various data sets are multiplied by arbitrary gain factors for clarity of presentation. The amplitudes are obtained from a series of FFT's over a two or three oscillation wide window. The straight lines are predictions of the normal state amplitude given the measured normal state parameters for this orbit. The preditions (and hence the derived values of Rs) are in fact reasonably robust, with a fair fit observed when plotted in B space rather than the 1/B plot shown here. It can be seen that the superconducting damping factor is increasing

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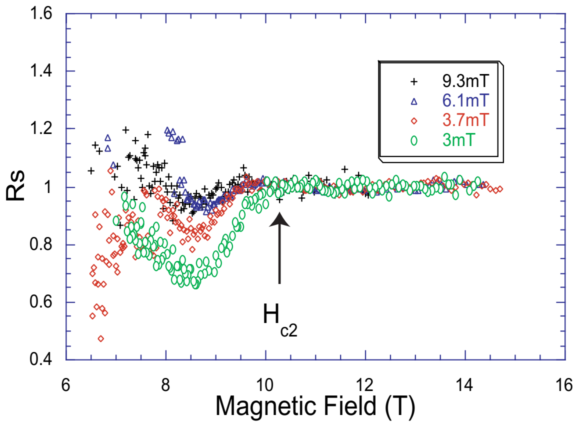

Fig. 1. The superconducting state damping factor, Rs for the 6912 T orbit as a function of field for several modulation amplitudes.

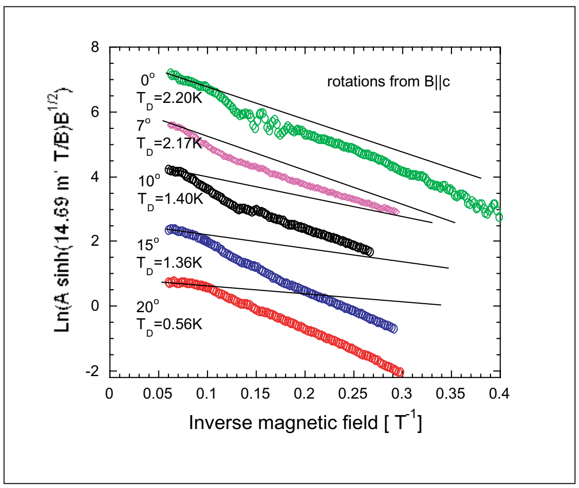

Fig. 2. Dingle plots of the 502 T (|| < 001 >) orbit of YNi_2B_2C as a function of angle. The straight lines are the expected normal state behaviour. It can be seen that the deviation of the superconducting state data from the expected normal state behaviour is changing with angle.

with angle.

Figure 3 shows the values of the superconducting gap parameter derived from the values of Rs as a function of angle. In performing the fits the modulation amplitude dependent data in the peak effect region was excluded. In plots (not shown) of the fit of Rs to the data the quality of the fit is not good. There are systematic deviations of the superconducting state date to the expected form. Such deviations are observed in many other materials and need clarification. However, providing we can qualitatively ascribe the behaviour of Rs to the variation of the superconducting gap parameter (as all theories do) it is clear that we observe an anisotropic gap parameter.

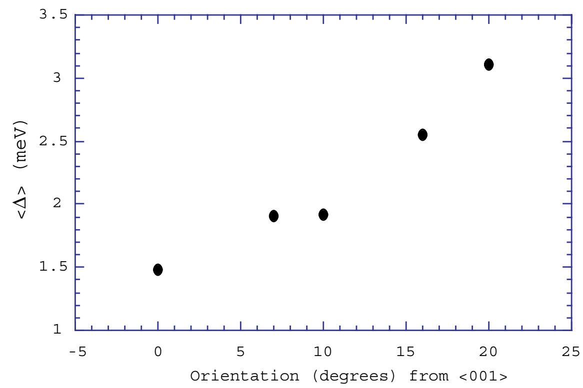

Fig. 3. Values of the orbitally averaged superconducting gap parameter, $<\Delta>$, as a function of angle from $< 001 >$ to $< 110 >$. The values are derived assuming the Maki and Wasserman formalism for dHvA amplitudes in the superconducting state.

In conclusion, we have measured dHvA in the superconducting mixed state of YNi_2B_2C as a function of crystal orientation. The results are generally consistent with earlier more limited studies. The orbitally averaged superconducting gap parameter has been obtained based on the field theoretic approaches of Maki and Wasserman. The values of $<\Delta>$ so obtained provide clear evidence for strong anisotropy of the gap. We believe that this is the first time that a measurement of the anisotropy of the superconducting gap has been resolved to a single Fermi surface sheet. Further data is needed to clarify the true gap symmetry.

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