NQR EXPERIMENTS ON SC-Y ALLOYS AT VERY LOW TEMPERATURES

L. Pollack, E.N. Smith and R.C. Richardson

Cornell Microkelvin Laboratory
Materials Science Center
Cornell University, Ithaca, New York 14853

We have performed Nuclear Quadrupole Resonance (NQR) experiments on an alloy of scandium and yttrium. We find that the characteristic resonance frequencies in zero external field are 50 percent larger than in pure scandium. This increase in frequency makes the Sc-Y alloy a better candidate for absolute thermometry below 500 μK. However, the spin-lattice relaxation time of this alloy is more than an order of magnitude longer than in the pure scandium. In addition, we have observed an abrupt increase in the Korringa constant for temperatures below 5mK.

1. INTRODUCTION

We have used NQR techniques to study the properties of nuclear spin systems with unequally spaced levels at zero applied magnetic field. These measurements can be made on systems with nuclear spin I > 1/2 when there is non-cubic symmetry in the lattice. Relaxation rates can be easily measured for these systems at zero external field. It will therefore be possible to study effects that are suppressed by the application of even a small magnetic field such as those due to impurities or other weak couplings. A second goal of this work is the use of these systems as absolute thermometers in the sub milliKelvin regime. The sensitivity of such a thermometer increases as a function of decreasing temperature over a sizeable temperature range. Finally the sign of the electric field gradient present in the crystal can also be determined by these techniques. Knowledge of this quantity as well as the size and sign of the electric quadrupole moment of the nucleus determines whether the ±m_I state or the ± 1/2 state has the lowest
We report the first observation of the pure NQR signal from Sc nuclei in a 50-50 Sc-Y mixture. We have made preliminary measurements of the spin-lattice relaxation times for this system. We find that the time constants that characterize the long time relaxation in this system are more than an order of magnitude longer than those measured for pure Sc. However, the NQR splitting in this system is 50 percent larger than in pure Sc which makes it a better candidate for absolute thermometry at higher temperatures.

2. BACKGROUND

Electric field gradients will exist in a crystal which has non-cubic symmetry. The two sources of this gradient are a non-cubic lattice, such as an hcp lattice, and a contribution from the non-s components of the conduction electron wavefunction. If the nuclear spin, I, is greater than 1/2 it possesses an electric quadrupole moment, hence the energy of the nucleus in the presence of this gradient will be dependent on its orientation with respect to the axis of field gradient. If the crystal is axially symmetric it can be shown\(^1\) that the nuclear energy levels in zero external magnetic field are

\[
E_{m_f} = \frac{e^2 qQ}{4I(2I-1)} (3m_f^2 - I(I + 1)).
\]

In this expression eQ is the electric quadrupole moment of the nucleus, and eq is the total electric field gradient present at the nucleus. From this equation it is clear that the levels for \(\pm m_f\) are degenerate.

Transitions between adjacent states can be induced by the application of a pulse of radiation at the correct frequency as in pulse NMR\(^2\). It is also possible to create spin echo signals by applying two consecutive pulses to the system.\(^3\) All of the work reported in this paper was done using the spin echo technique because of the very fast decay of the transverse magnetization.

3. APPARATUS

The measurements were made at the Cornell Microkelvin Laboratory. The cryostat consists of an Oxford Model 600 Dilution Refrigerator and an 80 mole copper nuclear demagnetization bundle. The details of the cryostat and spectrometer are given in reference 4. The samples were all mounted in the same manner as those described in that reference.