Ultrasound Study of Nuclear Ordered Solid Helium 3

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Nuclear magnetism of solid ^{3}He provided an extensive guide line to the concept of multiple spin ring exchange (MSE), which is becoming a common concept among highly correlated many body systems. At the ultra low temperature below about 1mK, there are two nuclear spin ordered phases: the low field U2D2 phase and the high field CNAF phase, which exists above $B_{c1}(T) \approx 0.45$ T. It is beleaved that the concept of the MSE is necessary to understand these two nuclear antiferromagnet. The exchange constants, J, depend strongly on molar volume, V, as $J \propto V^{20}$. Therefore studying acoustic properties of solid ^{3}He provides good information in understanding the MSE.

We measured the temperature and magnetic field dependences of sound velocities, v(T, B), in both phases with a single magnetic domain crystal at the melting pressure. Through the analysis on Δv(T, B) $\equiv$ v(T, B) - v(0, 0) for various sound propagation directions, we obtained six independent components of the temperature dependent nuclear spin elastic stiffness tensor $\Delta c_{ij}^{\mathrm{U}}(T, B = 0.06\ \mathrm{T})$ and the field dependent one $\Delta c_{ij}^{\mathrm{U}}(T = 0.5\ \mathrm{mK}, B)$ for the U2D2 phase, which has tetragonal symmetry. In the CNAF phase with cubic symmetry, we determined three independent components of $\Delta c_{ij}^{\mathrm{C}}(T, B = 0.50\ \mathrm{T})$, and $\Delta c_{ij}^{\mathrm{C}}(T = 0.5\ \mathrm{mK}, B)$. From these Δc_{ij}, we obtained the generalized Grüneisen constants, Γ_{ij}^{X} ($\equiv \partial^2 \ln X / \partial\varepsilon_i \partial\varepsilon_j$), where ε_i is a strain and X denotes a physical quantity such as the spin wave velocity c or the inverse susceptibility $1/\chi$. The obtained Γ_{ij}^{c} and $\Gamma_{ij}^{1/\chi}$ are compared with the theoretical constraint, which is derived from the three parameter MSE model. Using this comparison, the quantitative validity of the model is discussed.

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