Lattice Relaxation in Solid ^{4}He: Quantum Tunneling of Isotopic Impurities

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Introduction

The effect of lattice relaxation by two-phonon processes that accompanies the quantum tunneling of 3He impurities in sold ^{4}He has been calculated for the low temperature solid in the region where torsion oscillator studies lead some to believe that a supersolid state had been observed.

Theoretical Model

As a result of the larger zero point motion of ^{3}He impurities compared to ^{4}He atoms, in solid helium, a significant lattice distortion accompanies the impurity as it moves through the lattice. The dynamics of the impurity therefore depends on both the interaction with other ^{3}He impurities and on the relaxation of the lattice in the wake of the tunneling impurity. The relevant autocorrelation function is $G_{(ij),(kl)} =< T_{ij}^m (T_{kl}^m(t))^\dagger > = \frac{4}{x_3} < T_{ij}^m \exp[-i(H_K + H_J)t]\,(T_{kl}^m)^\dagger \exp[i\left((H_K + H_J)t\right] >$ where $T_{ij}{}^m$ is the tensorial operator equivalent of the spherical harmonic $Y_2{}^m(\theta_{ij})$ for the nuclear spin dipole-dipole interactions between ^{3}He particles at sites *i* and *j*. $H_K = K_0\left(1 - 3cos^2\theta_{ij}\right)$ is the anisotropic elastic deformation strain field at site i due to an impurity at site j with K_0 ~ 1200 MHz. H_J is the tunneling Hamiltonian. This leads to a correlation function for the field operators for the elastic field deformation at sites j and k given by the coupling between the elastic field gradient $K_{ij} - K_{jk}$ and the lattice phonons.

Results and Discussion

The calculated temperature dependence of the NMR relaxation times of ^{3}He impurities for concentrations of 16, 24 and 500 ppm) in solid ^{4}He is shown in Fig.1 for an empirical relaxation time $\tau = \tau_0 \exp(\frac{\Delta}{T})$. Δ is the ^{3}He-^{3}He binding energy. At high temperatures and high concentrations a temperature independent variation is observed [1] consistent with quantum tunneling. In the vicinity of 175 mK a smooth peak is observed [2] in the same temperature range where the other anomalies are observed. An excellent fit to the data for all three concentrations is obtained by including a thermally activated change in the lattice elasticity.

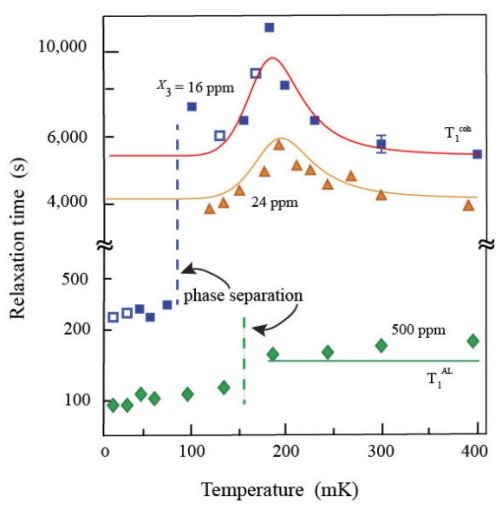

Figure 1. Comaprison of the calculated temperature dependence of the nuclear spin-lattice relaxation for ^{3}He impurities in solid ^{4}He with the observed values.

Conclusions

The temperature dependence of the nuclear spin-lattice relaxation of ^{3}He impurities in solid ^{4}He shows no evidence of the critical behavior expected for a supersolid transition and is consistent with an unusual quantum plastic property of the ^{4}He lattice.

Acknowledgements

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References

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[2] Sullivan, N. S.; J. Low Temp. Phys. **Online** Oct. 2103. doi 10.1007/s10909-013-0932-4