Annealing Effect for Supersolid Fraction in $^4$He

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Abstract We report on experimental confirmation of the non-classical rotational inertia (NCRI) in solid helium samples originally reported by Kim and Chan. The onset of NCRI was observed at temperatures below $\approx 400 \text{ mK}$. The ac velocity for initiation of the NCRI suppression is estimated to be $\approx 10 \text{ m/sec}$. After an additional annealing of the sample at $T = 1.8 \text{ K}$ for 12 hours, $\sim 10\%$ relative increase of NCRI fraction was observed. Then after repeated annealing with the same conditions, the NCRI fraction was saturated. It differs from Reppy’s observation on a low pressure solid sample.

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1 Introduction

Recently the observation of NCRI [1] in solid $^4$He reported by Kim and Chan [2–4] for samples confined in Vyvor, in porous gold, and also in bulk solid. The existence of NCRI was reported by Shirahama et al. [5] and by Rittner and Reppy [6] with torsional oscillator (TO) measurements. We report on our independent experiment [7] to check the existence of NCRI and related properties. In spite of very large differences of the surface to volume ratios in different samples, the NCRI fraction in low temperature limit was on the order of 1% for all reported cases. This indicates the observed phenomenon is not for a surface related one, but for a uniform system over length scales, 6 nm and larger. Nevertheless, a number of theoretical papers [8–13] suggest the superfluidity is unlikely to occur in a perfect crystal.
A possibility for Bose–Einstein condensation (BEC) of zero point vacancies was suggested by Andreev and Lifshitz [14]. If observed decoupling is a simple consequence of BEC of zero point vacancies, then the supersolid fraction should monotonically decrease as the pressure of solid sample increases from the melting curve and should not strongly depend on the sample quality. However the measured [15] pressure dependence of NCRI fraction was nonmonotonic with a maximum at \( \approx 55 \) bar. The absence of significant influence of annealing to the solid samples was pointed out by Kim and Chan [15]. Bose condensation of other types of imperfections, for example, interstitial-vacancy pair excitations as elementary excitations have been considered by Galli and Reatto [16], and imperfections at crystalline boundaries and dislocations are studied [10, 11]. In the latter case we can expect some influence of sample quality. A recent experimental result supports such an idea that supersolid is preferred in a disordered sample and annealing out such disorder would destroy supersolid state. The complete disappearance of NCRI after annealing was observed by Rittner and Reppy [6].

In the present report we confirm independently the existence of the NCRI with TO technique and also show a preliminary result of the annealing influence to the bulk solid \(^{4}\)He samples, which indicate the opposite result to the low pressure sample case reported by Ritter and Reppy [6].

2 Experimental Details

We use a TO made of BeCu25 alloy. The sample bob has a replaceable brass cover screwed and soldered with Wood’s alloy forming a cylindrical sample cell. Two types of cells have been used up to now. The difference between them is a small capacitance pressure gauge similar to described in [17] mounted only on the 1st cell. The torsional rod is 2.5 mm outer diameter, 0.8 mm inner diameter and 20 mm long. The TO was mounted on a copper block mechanical isolator which was connected to mixing chamber and was operated at small ac velocities in constant amplitude mode. The 1st and 2nd empty cell have resonant frequencies 1499.6 Hz and 1534.7 Hz, respectively. The filling line was connected to the torsion rod with minimum dead volumes to avoid the influence of the solid helium inside of the torsion rod. The solid sample was 8 mm in diameter and 4 mm in height. Taking into account the volume of the pressure gauge, the sample volume was 160 mm\(^3\) for the 1st cell and 200 mm\(^3\) for the 2nd.

The solid samples were prepared from commercially available \(^{4}\)He (\( \sim 0.3 \) ppm \(^{3}\)He impurity) by blocked capillary method at slow cooling (10–15 mK/min) along the melting curve to avoid appearance of the pressure gradient at crystallization. The sample 1 was annealed at \( T = 1.75 \) K overnight before the measurements. The frequency change due to the increase of inertia moment by the sample is in reasonable agreement with molar volume estimation (see Fig. 1).

In the sample 1 measurement we utilized our pressure gauge, but because of a large leak, appeared suddenly to the space between gauge electrodes, it started to work as a density gauge with a small sensitivity. We could still observe clear indication of the crystallization finish of the sample and estimate the final pressure of the sample. We could also see that the temperature inside of the cell has the synchronous behavior.