Torsional Oscillator Experiments of hcp Solid He with Hollow Torsion Rod

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Received: date / Accepted: date

Abstract We describe our torsional oscillator experiments to study hcp solid $^4$He samples[1, 2] and our new experience with modified torsion rod. Namely we want to study solid $^4$He without the effect of solid $^4$He sample in the torsion rod. In order to eliminate the signal from the He in the rod, we emptied it, instead we introduced a flexible CuNi tubing of 0.2/0.1 mm outer and inner diameters into the cell from the opposite direction. We noticed that this changed the obtained signal in a much cleaner manner. We plan to use it for further quantitative study of solid $^4$He for the vortex fluid(VF) state[1] as well as the 3D supersolid(SS)[2] state below $T_c$, including the experiment under DC rotation as well to clarify the result.

Keywords Vortex fluid · Solid He · Supersolid Transition · state above $T_o$

PACS 67.80.bd, · 67.25.dk · 67.25.dt

1 Introduction

The report on the evidence for quantized vortices and the vortex fluid (VF) state[1] in hcp solid $^4$He has been stirring the low temperature community. Additional reports on the possible transition from VF state into a 3D supersolid(SS) state[2] are further exciting the community, although there is neither a microscopic theory nor common understanding of the description of all the experimental observations reported so far for the solid $^4$He[3]. Yet, we can ask ourselves still quite simple questions as we discuss here. Namely, what is the state above the onset temperature $T_o$, below which quantized vortices starts to appear? In electronic systems there have been reports describing the state above superconducting transition $T_c$ [4], or above the onset temperature $T_s$, below which also quantized vortices appearance is being discussed. There are examples
Fig. 1 FIG. 1 (color online). T dependence of energy dissipation $\delta$ (a) and $\Delta p/\Delta p_{\text{load}}$ (b) at various $V_{ac}$ in $\mu$m/s for a 32 bar sample (from [1]). The values of $\delta$ are presented without any articial shift. Some data are omitted for clarity. An arrow indicates $T_0$, across which $V_{ac}$ dependence changes. The inset in (a) indicates a typical energy dissipation peak with somewhat higher $T_p$. The low $T$ part of the peak was fitted with a Gaussian: dashed line. The zero for $\Delta p/\Delta p_{\text{load}}$ in (b) is taken provisionally where $V_{ac}$ dependence goes away.

of electronic solid state of charge density wave state or spin density wave state [5]. Then, what about in solid $^4$He? There has been no such questions asked so far because there were no convincing experimental report of vortex fluid state in hcp solid $^4$He except our work [1,2].

2 State above $T_0$ in hcp solid $^4$He

We are very much interested in the question of the state above $T_0$ in hcp solid $^4$He, because it is not easy to imagine or to expect quantized vortices in a usual solid state. $T_0$ can be interpreted as a sort of the low dimensional Bose Einstein Condensation (BEC) temperature in the restricted geometry, where mobile particles condense into a coherent state over some length scales so that quantized vortices can be thermally activated. So the even the state above $T_0$ should provide mobile particles, as in the normal fluid
Fig. 2 (Color online) TO setup with hollow torsion rod, which is realized by blocking the path through the rod using a Cu piece to our TO used in [1, 2]. An extra filling line of 0.2/0.1 mm diameter is attached on the other end of torsion bob as seen in the photo.

State of liquid He, or in metallic state above superconducting transition. This question may be connected to the wider interest in the question of state above superconducting transition at $T_c$ in Cuprate superconductors, organic superconductors, and layered superconductors and so on including newly found Fe compounds superconductivity. Quite often superconducting transition is preceded by charge density wave state, spin density wave state and so on with rather strong fluctuations. What about in hcp solid $^4$He?

We are trying to study hcp solid He above $T_o \simeq 0.5$ K. Then we realize that all the experimental data by torsional oscillator technique about this temperature range we find some peculiarity regardless by which group they are measured. Some people omit this $T$ range from the plot of the data. We find in our data there are always some peculiar $T$ dependence as seen in Fig. 1. On the other hand, there had been measurements of solid $^4$He, where solid $^4$He sample was intentionally put in the torsion rod to study the dislocation motion and properties under stress in solid $^4$He [9]. In the present study we tried to eliminate the effect of solid $^4$He in the torsion rod by closing up the rod with vacuum. In order to realize this we needed to install a new filling line for the sample $^4$He.

3 TO with hollow torsion rod

Fig. 2 shows our TO setup with hollow torsion rod and extra He filling line provided by a rather thin CuNi capillary of 0.2/0.1 mm outer/inner diameter. Our intention is to eliminate the TO signal contribution from the solid $^4$He sample in the TO rod. In our design space in the torsion rod is blocked by Cu piece, which functions as the new cell wall and sealed with fine pitch screws and Wood’s metal soldering in a similar manner as in[1]. A new filling line is installed at the other end of the torsion bob as seen in the photo in Fig. 2. The line is made of CuNi annealed capillary, with its free motion.
Fig. 3 (Color online) Preliminary torsional oscillator (TO) with hollow torsion rod measurement data for 41 bar hcp $^4$He sample together with liquid at 11.1 bar. There is a clear indication of energy dissipation change above 0.5K for the liquid data in the upper column. This drastic change for the liquid data is accounted for by roton excitations. Except for the roton excitation, there is no change near 0.5-0.6 K. This is contrasted with Fig. 1.

Fig. 3 indicates our preliminary TO results with a 41 bar solid $^4$He sample together with liquid at 11.1 bar, measured with the new setup with empty torsion rod. The upper column shows Amplitude/Vex data which corresponds roughly the Q value divided by a few times$10^4$. And the lower column shows the period. We realize the disappearance of the rapid change of TO responses above near 0.5 K, which were present in our previous results (Fig. 1, for example) as well as in other groups' results [7, 8]. We observe that the TO signal with liquid $^4$He shows rather rapid change in the Amplitude/Vex above about 0.5-0.6K and this is interpreted as the roton excitations effect in the superfluid capability we gained reasonably high Q value between half a million and a million, but started with about $10^5$. An improvement is achieved largely by vibration isolation in the cryostat by the filling line.
$^4$He. Such a change goes away when we measure solid samples. Irregular dependence, which appears in both columns in Fig.3 can be removed by careful and time consuming process as realized in our 32 bar sample measurements[1]. We are making a progress to study more quantitatively the various properties of hcp solid $^4$He, through which we hope to find out microscopic origin and mechanism of the whole phenomena occurring in the simple quantum solid, $^4$He.

We have been performing quantitative study of TO responses from hcp $^4$He samples under quite systematic conditions, and we have come to the point to discuss systematic study of the vortex fluid state[1] as well as 3D macroscopic supersolid(SS)[2] by studying the responses in terms of dynamics of quantized vortices[6]

Acknowledgements Authors acknowledge the important contribution to the present work by Andriy Penzev at the initial stage.

References

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http://cdsagenda5.ictp.trieste.it/fulldisplay.php?ida=a07168, see also the following url: