CD 56

Fast Diffusion Process in Quenched hcp Dilute Solid ^3He-^4He mixture

Ye.Vekhov, A.Birchenko, N.Mikhin, and E.Rudavskii

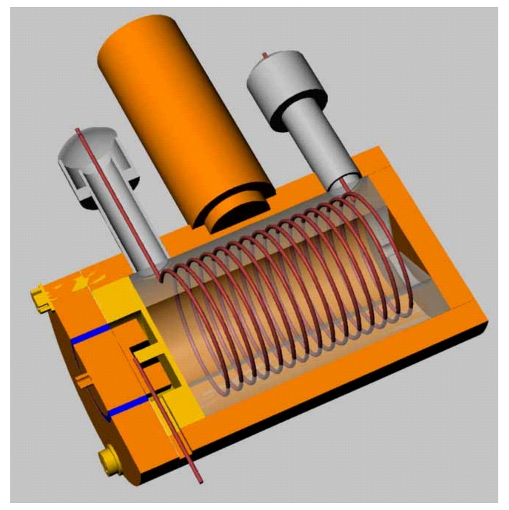
Vekhov@ilt.kharkov.ua

B.Verkin Institute for Low Temperature Physics and Engineering of the National Academy of Sciences of Ukraine

Motivation

NMR technique allows to measure diffusion coefficient in different coexisting phases and difference of diffusion coefficients in liquid and solid helium are several orders of the magnitude then such an experiment may answer the question – whether liquid inclusions are formed in solid helium under very rapid crystal growing. The aim of present work is to elucidate this problem.

Experimental technique



body (Cu)
specimen cavity (l=14mm, Ø=6mm)
capacity pressure gauge (BeCu)
NMR coil

Experimental procedure

- **Object** — 1% ^{3}He in ^{4}He solid mixture
- **Grown technique** — blocking capillary
- **Measurements** — precise pressure measurement (acuracy 5 mbar, resolution 1 mbar) and NMR technique
- **Annealing** — 3 stages (on the melting curve, at the temperature 5-25 mK below the melting curve, and thermocycling in one-phase region)
- **Temperature range** — 1.2 - 2.0 K
- **Pressure range** — 34.0 - 38.0 bar

NMR technique

The Carr-Purcell (CP) spin-echo method was used with a 90° - tau - 180° sequence of probe pulses

$$\frac{h}{h_0} = \sum_i \alpha_i \exp\left(-\frac{2}{3}\gamma^2 G^2 \tau^3 D_i\right) \qquad (1)$$

The method of stimulated echo (SE) with the sequence of three probes pulses 90° - tau$_1$ - 90°- tau$_2$ - 90°

$$\frac{h}{h_0} = \sum_i \alpha_i \exp\left[-\gamma^2 G^2 D_i \tau_1^2 \left(\tau_2 - \frac{\tau_1}{3}\right)\right] \qquad (2)$$

Results

Melting curve

Liquid +Solid

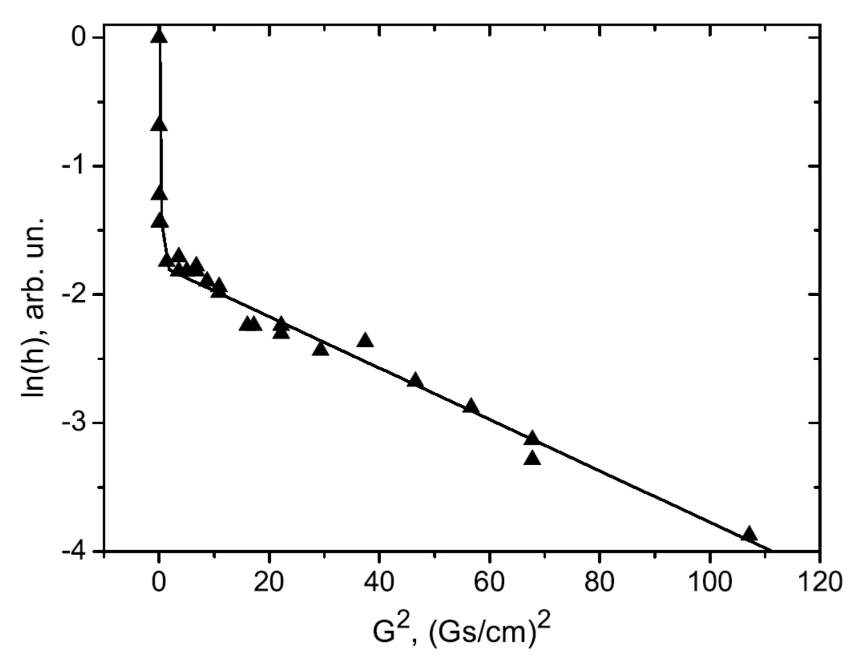


Fig. 1 - Diffusion decay of spin-echo in hcp crystal on the melting curve, 2.10 K, 45.0 bar. Points – experimental SE data for tau$_1$ = 80 ms, tau$_2$ = 1 s, $D_L = 1\cdot10^{-5}$ cm^2/s, $D_h = 1.8\cdot10^{-8}$ cm^2/s; the solid line – fitting to Eq. (1).

Quenched HCP solid (without annealing)

17% of liquid-like inclusions and pressure relaxation during 0.5 - 2 hour

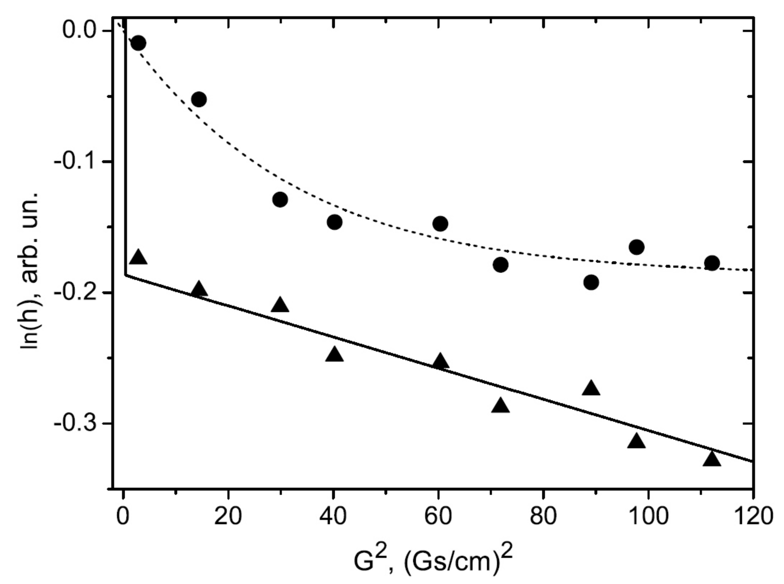


Fig. 2 - Diffusion decay of spin-echo in quenched hcp crystal, 1.3 K, 35.0 bar. Solid circles – CP data for tau = 25 ms, $D_L=1\cdot10^{-4}$ cm^2/s, solid triangles – SE data for tau1 = 14 ms, tau2 = 20 s, $D_h=8\cdot10^{-10}$ cm^2/s. The dashed line – fitting to Eq. (1); the solid line – fitting to Eq. (2).

Slow cooled HCP solid after annealing: No Liquid

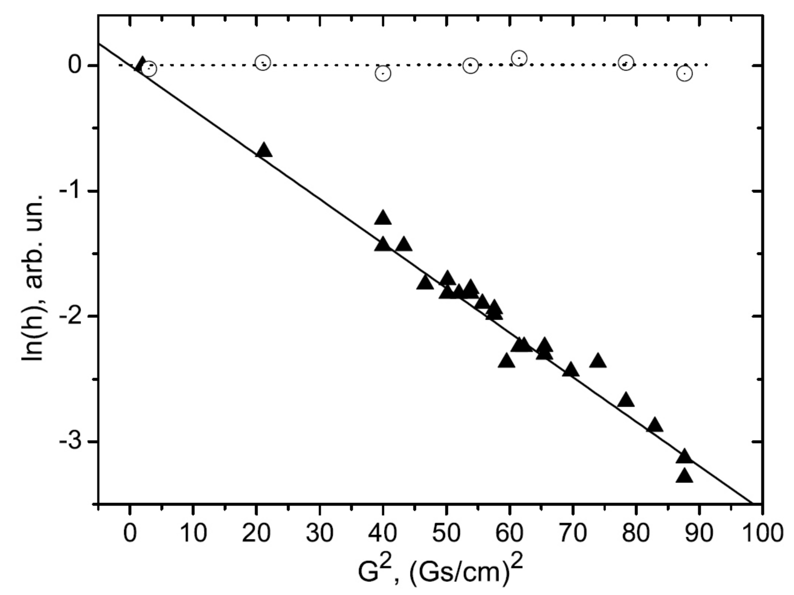


Fig. 3 - Diffusion decay of spin-echo in good annealed and slowly cooled hcp crystal, 1.3 K, 35.0 bar. Empty circles – CP data for tau = 20 ms; solid triangles – SE data for tau$_1$ = 70 ms, tau$_2$ = 20 s, D_h = $8.7\cdot10^{-10}$ cm^2/s; the dotted line – fitting to Eq. (1); the solid line – fitting to Eq. (2).

For notes

Abstract

The spin diffusion coefcient of 1 % ^{3}He in hcp ^{4}He has been measured at pressure over 35 bar in the temperature interval from 1.2 K up to melting curve. The applied spin echo NMR technique does allow to distinguish the contributions from both of coexisting phases on the melting curve: normal liquid and hcp solid. The results of the measurements in annealed solid samples are in a good agreement with available data - only one diffusion process is available in hcp phase. On the contrary, investigations of crystals created by quench of liquid ^{3}He - ^{4}He mixture showed additional fast diffusion process which may be attributed to a presence of considerable quantity of liquid phase (~ 10% of the volume, dffusion coefcient ~ 10^5 cm^2/s) keeping down to the lowest temperature. This suggestion is discussed from the point of view of both early observation [1,2] of ~ 20 mkm size liquid-like droplets which appear at bcc/hcp region in ^{3}He - ^{4}He solids, and the newest observation of tangles of dendrites growing under rapid temperature quench of normal liquid helium [3,4].

1. N. Mikhin, A. Polev, and E. Rudavski, JETP Letters, 73, 470 (2001).
2. A. Polev, N. Mikhin, and E. Rudavskii, JLTP, 127, 279 (2002).
3. S. Sasaki, F. Caupin, and S. Balibar, Proceeding of LT-25, 146, Amsterdam (2008).
4. S. Sasaki, F. Caupin, and S. Balibar, Proceeding of LT-25, 275, Amsterdam (2008).

Conclusions

It is shown that under rapidly cooling from the melting curve (without annealing) solid helium samples contain liquid-like inclusions identified by additional fast diffusion decay of echo-signal. Subsequent annealing of these samples leads to fast diffusion disappearing which is connected with crystallization of liquid-like inclusions. Coming out of these defects is accompanied by pressure relaxation in the system.

Acknowledgments

The authors thank QFS Organizing Committee for support.
The work was also supported by STCU Grant #3718, Program of Cooperation in Research and Education in Science and Technology for the 2008 Ukrainian Junior Scientist Research Collaboration (CRDF), and the Ministry of Education and Sciences of Ukraine (Project #M/386-2009)