Welcome to ISSP, the University of Tokyo and to

ISSP WorkShop
on
Quantum Solid properties, the Supersolid state, and the Vortex State

Kashiwanoha, Kashiwa, Chiba, Japan, 5-6, March 2010

Kashiwa Campus of the University of Tokyo, May 2009

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Welcome to ISSP, the University of Tokyo and to

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The present workshop plan was born out of personal discussions among the people who were interested in the research development and actual happenings in a Quantum solid, hcp ^{4}He, during and after Supersolid Workshop at Banff(2009)(http://www.phys.ualberta.ca/supersolids/), Canada. It is one of a series of workshops on the subject since the first one in February 2006 at KITP, Santa Barbara, California USA(http://online.itp.ucsb.edu/online/smatter_m06/). Our plan was initially just a small gathering. Following the Institute for Solid State Physics(ISSP)’s offer of support and many people’s declaration of interest, it has grown to become a real workshop. We could organize it as a real forum to discuss these fundamental simple questions: What is the essence of the solid state properties, especially the quantum solid state? What should supersolid state be? And what kind of quantized vortices and vortex state would be in such a system? We will hear 14 presentations in the following categories:

Scope and Subjects of the workshop

Bulk hcp He (Experimental)

1]. Eunseong Kim, “Can supersolid be suppressed in stiffened solid ^{4}He?” [**B7**]

2]. Minoru Kubota, "A Torsional Oscillator Study of Quantized Vortex State in hcp ^{4}He under AC and DC Rotation" [**A2**]

3]. Ryo Toda, "Simultaneous measurement of Torsional Oscillator and NMR of Extremely Diluted ^{3}He in Solid ^{4}He." [**A1**]

Bulk hcp He(Theoretical)

4]. Izumi Iwasa, "Dislocation model for nonclassical rotational inertia" [**A3**]

5]. Sergey Nemirovskii, “How the vortex tangle can be involved into rotation and torsional oscillation”. [**A4**]

6]. Makoto Tsubota, “Model of supersolids by the nonlocal Gross-Pitaevskii like equation”. [**A5**]

7]. Anatoly Kukulov, "Interconnection of mechanical and superfluid properties of solid He^4". [**A6**]

8]. Nina Krainyukova, "Delocalization via sliding and 2D vorticity in solid ^{4}He". [**B2**]

Solid He in restricted geometry

9]. Keiya Shirahama, “Supersolid Behaviors in Thin "Rods" and "Films" of Solid ^{4}He in a Nanoporous Glass”. [**B5**]

10]. Yuichi Okuda, “Thermal and quantum crystallizations of $_4$He in aerogel”. [**B6**]

Experimental Glass transitions/ Quantum phenomena in Other systems?

11]. Osamu Yamamuro, "Experimental studies on glass transitions and dynamics of supercooled liquids". [**B1**]

12]. Shuji Harada, “Possible quantum phenomenon of hydrogen in Pd-H system”. [**A7**]

Slippages

13]. Masaru Suzuki, "Slippage and 2D superfluid, experiment ". [**B3**]

14]. Tomoki Minoguchi, "New dynamics of He-4 films on graphite ----Superfluid dynamics coupled with solid bilayer----" [**B4**]

Programm Time Table

5th March 2010

13:00 Registration start
13:30 Opening Remarks

Bulk hcp He (Experimental)

13:40 **A0** Eunseong Kim and Minoru Kubota, Introduction to "Quantum solid, the Supersolid state, and the vortex state"
14:20 **A1** Ryo Toda, "Simultaneous measurement of Torsional Oscillator and NMR of Extremely Diluted ^{3}He in Solid ^{4}He.
15:00 **A2** Minoru Kubota "A Torsional Oscillator Study of Quantized Vortex State in hcp ^{4}He under AC and DC Rotation"

Coffee Break 15:40-16:00

Bulk hcp He (Theoretical)

16:00 **A3** Izumi Iwasa, "Dislocation model for nonclassical rotational inertia"
16:40 **A4** Sergey Nemirovskii, "How the vortex tangle can be involved into rotation and torsional oscillation?"
17:20 **A5** Makoto Tsubota, "Model of supersolids by the nonlocal Gross-Pitaevskii like equation"
17:40 **A6** Anatoly Kuklov, "Interconnection of mechanical and superfluid properties of solid He4".

Break 18:20-18:30

18:30 - 19:30 Banquet

Evening Session:

Some other possibilities?

19:30 **A7** Shuji Harada,"Possible quantum phenomenon of hydrogen in Pd-H system"

20:10 **A8** Discussion
21:00 End of the 1st Day

6th March 2010

Experimental Glass transitions

9:00 **B1** Osamu Yamamuro, "Experimental studies on glass transitions and dynamics of supercooled liquids"

Slippage and Restricted Geometries

9:40 **B2** Nina Krainyukova, "Delocalization via sliding and 2D vorticity in solid ^{4}He". (Theory)

Coffee Break 10:20-10:50

10:50 **B3** Masaru Suzuki, "Slippage and 2D superfluid, experiment "
11:30 **B4** Tomoki Minoguchi, "New dynamics of He-4 films on graphite ---- Superfluid dynamics coupled with solid bilayer----" (Theory)

Photograph and Lunch 12:10- 13:30

13:30 **B5** Keiya Shirahama, “Supersolid Behaviors in Thin "Rods" and "Films" of Solid ^{4}He in a Nanoporous Glass”

14:10 **B6** Yuichi Okuda, “Thermal and quantum crystallizations of ^{4}He in aerogel”

Bulk hcp He (Experimental)

14:50 **B7** Eunseong Kim, “Can supersolid be suppressed in stiffened solid ^{4}He?"

Coffee Break 15:30 - 15:50

15:50 **B8** Discussions and Summary

What Have we learned?
Bulk hcp He, what are the specifics?
Same physics as in restricted geometry?
Slippage in the film, also in the bulk?
Evidencies of quantized vortices and vortex state?
Hardening and supersolid?
Do we expect some other supersolid state in other systems?
What is the connection to a glass transition, if any?

~17:00 **End of the workshop**

A0 Eunseong Kim and Minoru Kubota,

Introduction to "Quantum solid, the supersolid state, and the vortex state"

Part A: by E. Kim

Since the discovery of supersolid, a quantum solid exhibiting superfludidity, in helium in 2004, many research groups have focused on understanding this exotic new state of matter. Despite the intense efforts of theorists and experimentalists, many open questions remain, for example the microscopic mechanism of supersolidity, the role of crystal defects and disorder, and the relationship between shear modulus anomaly and non-classical rotational inertia. In this presentation, the early experimental developments in supersolid phenomenon will be briefly discussed.

Part B: by M. Kubota

The program of the whole workshop will be briefly introduced, and some technical information will be given.

A1 Ryo Toda,

Simultaneous measurement of Torsional Oscillator and NMR of Extremely Diluted ^{3}He in Solid ^{4}He.

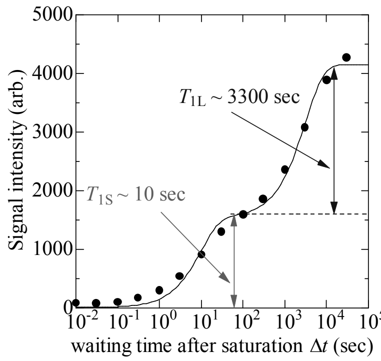
R. Toda[1,2], W. Onoe[1], P. Gumann[2*], M. Kanemoto[1], K. Kosaka[1], T. Kakuda[1], Y. Tanaka[1], and Y. Sasaki[1,2]

[1]*Department of Physics, Graduate School of Sciences, Kyoto University, Sakyo-ku, Kyoto 606-8502, Japan*
[2]*Research Center for Low Temperature and Materials Science, Kyoto University, Sakyo-ku, Kyoto 606-8501, Japan*

Superfluid-like behavior of solid ^{4}He was discovered as missing rotational inertia which is usually referred as non-classical rotational inertia (NCRI) by the torsional oscillator experiment [1]. Since then, a lot of theoretical and experimental studies have been done by many research groups. Among the many experimental results, the most peculiar observation is that the NCRI response and onset temperature are affected strongly by the tiny amount of ^{3}He impurities [2]. The NCRI response disappears when solid ^{4}He contains just a hundred ppm of ^{3}He impurities. This is unreasonably small amount of impurities to destroy the phenomenon if we consider the NCRI as non-magnetic macroscopic phenomenon in solid ^{4}He like superfluid ^{4}He.

In order to study the physics in behind of this peculiar phenomenon, we have developed an apparatus to measure the torsional oscillator response and NMR response for the same solid ^{4}He with dilute ^{3}He impurities. NMR measurement of ^{3}He provides the information on the state of ^{3}He in solid ^{4}He. It is well known that in the solid mixture system, phase separation occurs at low temperature [3]. Below the phase separation temperature T_{PS}, ^{3}He atoms form clusters in solid ^{4}He, and the size of clusters grow up slowly to a few μm in the case of a few % of ^{3}He sample [4]. In our torsional oscillator experiment, commercial grade ^{4}He (0.3 ppm of ^{3}He) at 3.6MPa shows the NCRI fraction of 0.06% at T=0. For the sample of ^{4}He with a few hundred ppm of ^{3}He at 3.6MPa, NCRI response is smashed away. These results are consistent with the observations by other groups. We did not observe any signature on the torsional oscillator frequency near T_{PS}. Thus the phase separation may not be related with NCRI response directly.

We have investigated the NMR properties of ^{3}He with this concentration as well as samples with 300ppm, 100ppm, and 10ppm of ^{3}He. Our results show that three different states of ^{3}He exist in solid ^{4}He below T_{PS}. One corresponds to the isolated ^{3}He atoms in solid ^{4}He. Since it has extremely long longitudinal relaxation time T_1 (over a day) at low temperature, we could not investigate the details of this state. Other two components grow up with time after cooling below T_{PS}. Thus both components of ^{3}He correspond to phase separated clusters in solid ^{4}He. The T_1 values of each component provide a distinction between each components. Both clusters disappear above T_{PS}. However, the (S) component, which is identified by shorter T_1, recovers much faster than the other (L) component, after the solid is cooled down below T_{PS} again. It suggests that the extra trapping potential works in the place where (S) exists, so that the ^{3}He atoms in (S) component stay in the same region even above T_{PS}. Such a trapping potential may come from the macroscopically disordered part of solid ^{4}He.



Strong ^{3}He impurity effect on NCRI exists below and above T_{PS}. But, it is unlikely that the isolated ^{3}He atoms which locate separately with mean distance of 20 ^{4}He atoms for the case of 100ppm concentration, play a significant role in destroying NCRI response. However, if the NCRI response comes from the disordered part of solid ^{4}He where some ^{3}He atoms are concentrated in, tiny amount of ^{3}He plays a significant role in destroying NCRI response.

[1] E. Kim and M. H. W. Chan, Nature **427**, 255 (2004)
[2] E. Kim, *et. al.*, Phys. Rev. Lett. **100**, 065301 (2008).
[3] D. O. Edwards and S. Balibar, Phys. Rev. B **39**, 4083 (1989)
[4] M. Poole and B. Cowan, J. Low Temp. Phys. **134**, 211 (2004).
*Present address: Department of Physics and Astronomy, Rutgers University, Piscataway, NJ 08854-8019, U.S.A

Ryo TODA <rftoda@scphys.kyoto-u.ac.jp>

A2 Minoru Kubota

A Torsional Oscillator Study of Quantized Vortex State in hcp ^{4}He under AC and DC Rotation

Nobutaka Shimizu,[1] Sergey Nemirovskii,[2] Akira Kitamura[3], Yoshinori Yasuta[1], and Minoru Kubota[1]

[1] *Institute for solid State Physics, University of Tokyo, Kashiwanoha 5-1-5, Kashiwa, 277-8581, Japan*

[2] *Institute of Thermophysics, Lavrentyev ave. 1, 630090 Novosibirsk, Russian*

[3] *Graduate School of Science and Technology, Niigata Univ. Niigata 950-2181, Japan*

In the late 1960's, Proposals for the supersolid state in quantum solids like solid ^{4}He where the coexistence of the real space ordering of the lattice structure of the solid and the momentum space ordering of the superfluidity was discussed based on the Bose Einstein Condensation (BEC) of the imperfections as vacancies, interstitials and other possible excitations in the quantum solids. Since then new types of superfluidity have been discovered after the above original proposals in different systems. Namely, a real 2 dimensional (2D) superfluid transition has been established both in the theories and experiments for the He monolayer superfluid. A new type of superconductors, initiated by the discovery of the cuprate superconductors, is being discovered with a common feature of the vortex state, involving vortex fluid and vortex solid states, often discussed in connection to the 2D subsystem superfluidity, for example CuO_2 plane electronic system for the cuprate high T_c superconductor(HTSC)'s. A series of artificial 3D superfluids is being produced out of He monolayer systems. The high temperature transition temperature T_c of the above superconducting materials are being discussed in connection to the large fluctuations associated with some other phase transitions such as the antiferromagnetic transition in addition to that of the low dimensionality of the sub-system.

We review the recent experimental observations of hcp solid ^{4}He using highly sensitive and stable torsional oscillator(TO) techniques without[1-3] DC rotation and under DC rotation[4]. Our TO technique uses an AC oscillation with resonance frequency at around 10^3 Herz. A detailed study of the excitation velocity V_{ac} dependence of the TO responses of hcp He samples at 32 bar and 49 bar pressure showed a unique onset temperature T_o at about 500 mK, below which significant Vac dependence appears, which suggests pre-existing fluctuations in the system and by the AC excitation the fluctuations are reduced. A detailed analysis in terms of tangled quantized vortices lead to the quantitative parameters describing the tangled vortex dynamics and we interpret this state as a vortex fluid state[5]. This state is characterized by the non linear rotational susceptibility NLRS spontaneous fluctuations, which can be depressed by excitations according to log Vac dependence at large excitations. This strong AC velocity dependence was discussed by P. W. Anderson [6] and it describes the suppressed fluctuations by the introduction of vortex lines by the strong excitation.

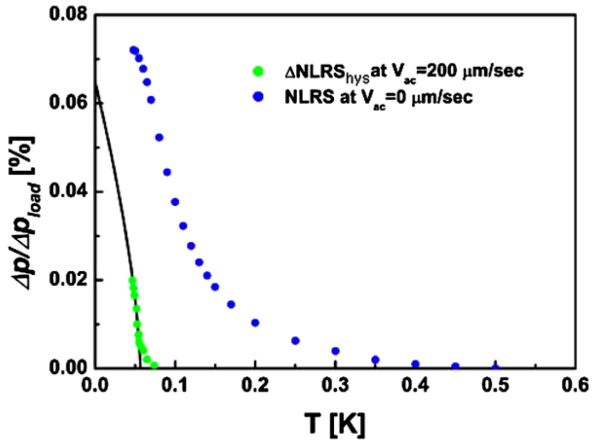


Fig. 1. Supersolid density $\rho_{ss}(T)$ (green dots), and NLRS at V_{ac} -> 0 (blue dots), vs T. See text and Ref. 2 & 3 (from Ref. 2).

A clear transition was found by the appearance of the hysteretic behavior below a characteristic temperature T_c for the first time in the same sample where vortex fluid state was first observed below T_o and below this T_c a new phase appeared. This phase is defined by characteristic AC velocities, V_h above which hysteresis appears and V_c beyond which the hysteretic component is sup-pressed to zero. We could also evaluate the 'supersolid density ρ_s' in the absolute units and from this obtain the value of the Josephson's length ξ at each temperature and even to extrapolated value of ξ to zero temperature ξ_0. This length ξ would be the vortex core diameter. And the critical velocity V_c to destroy supersolidity would be related to $V_c=h/(m_4\ \xi_0\ \pi)$ at T=0. Our independent observation of V_c and ξ_0 gives us a consistent picture[3]. Furthermore TO response under DC rotation[4] gave us evidence of quantized vortex lines penetration in the same sample below T_c, where we expect macroscopic coherence of the supersolid state [3, 4].

[1] A. Penzev, Y. Yasuta and M. Kubota, Phys. Rev. Lett. 101, 065301 (2008).
[2] M. Kubota, N. Shimizu, Y. Yasuta, P. Gumann, S. Nemirovskii, J Low Temp Phys, 158: 572–577 (2010).
[3] N. Shimizu, Y. Yasuta, and M. Kubota, arXiv:0903.1326v3 (2009).
[4] N. Shimizu, et al.,Meeting Abstracts PSJ vol.63, Issure2, Part4, 2008. 21pYE-13 (2008).
[5] S. Nemirovskii, N. Shimizu, Y. Yasuta, and M. Kubota, arXiv: 0907.0330v3(2009).
[6]. P.W. Anderson, Nature Physics, Vol. 3, 160 (2007).

e-mail: kubota@issp.u-tokyo.ac.jp

A3 Izumi Iwasa

Dislocation model for nonclassical rotational inertia

Izumi Iwasa
Fuji Xerox Co., Ltd.

Kim and Chan found that the moment of inertia of solid ^{4}He in a torsional oscillator decreased at low temperatures. By analogy with the superfluid transition of liquid ^{4}He they ascribed the phenomenon to a supersolid transition of solid ^{4}He. On the other hand, Day and Beamish observed that the shear modulus of solid 4He increased at low temperatures. They explained the variation of shear modulus in terms of dislocations pinned by ^{3}He atoms. There are similarities between the variations of moment of inertia and shear modulus, such as the onset temperature, the amplitude dependence, the dependence on ^{3}He impurity concentration x_3 and the accompanied dissipation peak.

The equation of motion for a TO containing solid helium is given by

$$I_{TO}\frac{d^2\phi}{dt^2} = -\kappa\phi + \tau \quad (1)$$

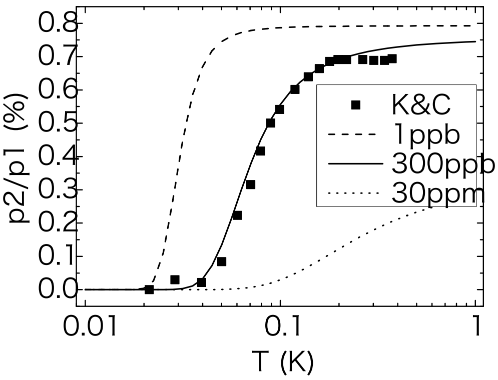
I_{TO}: moment of inertia of TO
φ: rotational angle
κ: spring constant
τ: torque on TO from solid helium

By using the elasticity theory and the Granato-Lucke dislocation theory, the period change of the TO is obtained to be

$$\frac{p_2}{p_1} = 0.11\Omega\Lambda L^2 \quad (2)$$

p_1: period change due to mass loading
Ω: orientation factor
Λ: dislocation density
L: average pinning length

L is an average of the network pinning length L_N and the impurity pinning length Li. The figure shows p_2/p_1 at different x_3 calculated from eq.(2) and an experimental data at x_3=300ppb (Kim & Chan, PRL 97, 115302(2006)). Fit parameters are $L_N=2.0\times10^{-6}$m and $\Omega\Lambda=1.78\times10^{10}\text{m}^{-2}$.



The dissipation is given by

$$Q^{-1} = 2\Delta_a \frac{\omega B}{A^2\omega_0^{\,4} + \omega^2 B^2} \quad (3)$$

Δ_a: prefactor
ω: angular frequency of TO
ω_0: resonance frequency of dislocation
A: effective mass of dislocation
B: damping constant

A simple model ($B\propto 1/$ Li) can describe the experimental results.

e-mail:
Iwasa-Izumi <iwasa@mva.biglobe.ne.jp>

A4 Sergey Nemirovskii

Torsional Oscillation of the Vortex Tangle

Sergey K. Nemirovskii[1,2], Nobutaka Shimizu[1], Yoshinori Yasuta[1], and Minoru Kubota[1]
1Institute for Solid State Physics, University of Tokyo, Kashiwa, Chiba277-8581, Japan
2Institute of Thermophysics, Lavrentyev ave., 1, 630090, Novosibirsk, Russia

One of the striking facts in study of the "supersolidity" is that it is observed only in unsteady situations. For us this fact is the absolutely definite proof, that there are some transient, or relaxation processes inside the solid helium. What is the nature of this relaxation is real enigma. Unless the rigorous theory is created, any phenomenological supposition (viscoelastic mode, Superglass State etc.) can be considered and discussed as a possibility.

But, if we accept (at least hypothetically, at this stage) that the phenomenon of "supersolidity" (dissipation-less flow) is realized, we must consider the relaxation of the vortex system (we can call it vortex tangle, vortex fluid, chaotic set of vortex etc.). We have to do it for the very simple reason, that the only way to involve the superfluid component into rotation is just through polarized vortices (with nonzero mean polarization along the axis of rotation). To distinguish the different approaches, to choose the more plausible, one has to arrange experiments with new controllable parameters. The changing of the rim velocity V_{ac} gives a unique opportunity to select out the different approaches[1]. The point is that (it is our key proposal) the relaxation (inverse) time is the sum of dependent and independent (on the rim velocity) parts. This results in the nontrivial (e.g. non-monotonic) behavior of the dissipation ΔQ^{-1} as a function of the applied velocity V_{ac}.

In the present talk we consider the approach describing the vortex fluid relaxation model for torsional oscillation responses of quantum systems having in mind to apply it for study of solid ^{4}He [2]. Utilizing a well-studied treatment of dynamics of quantized vortices we describe how the "local superfluid component" is involved in rotation (torsion oscillations) via a polarized vortices tangle. The polarization in the tangle appears both due to alignment of the remnant or thermal vortices and due to the penetration of additional vortices into the volume. Both are supposed to occur in a relaxation manner and the inverse full relaxation time τ^{-1} is the sum of them.

$$\tau^{-1} = \alpha(T)V_{ac}/R + \beta(T) \qquad (1)$$

{Here α(T) and β(T) are the (temperature dependent) parameters of the theory, R is the size of the solid ^{4}He sample}. In the presence of relaxation the angular momentum M(t) of the superfluid part is related to the applied angular velocity Ω(t) by the nonlocal relation, φ(t′) is the relaxation function.

$$\mathbf{M} = a\mathbf{\Omega}(t) + b\int_0^\infty \mathbf{\Omega}(t-t')\varphi(\frac{t'}{\tau})\frac{dt'}{\tau}. \qquad (2)$$

Equations of motion of the torsional oscillator in presence of nonlocal relation (2) are a set of integro-differential equations.Putting the relaxation function φ(t′) to be a purely exponential one φ(t′/τ)= exp(−t′/τ), and using the smallness of the superfluid moment of inertia I_{SF}, in comparison with the full moment of inertia I_{Full}, we find that the drop of period $\Delta P/P$ and dissipation are

$$\frac{\Delta P}{P} = -\frac{1}{2}\frac{I_{SF}}{I_{full}}\frac{(\omega\tau)^2}{(\omega\tau)^2+1}. \qquad (3)$$

$$\Delta Q^{-1} = \frac{2\Im(\omega)}{\omega} = \frac{I_{SF}}{I_{full}}\frac{(\tau\omega)}{\tau^2\omega^2+1} \qquad (4)$$

Relations (3),(4) are the final solution to the problem of the torsional oscillation when the superfluid component is involved in rotation via polarized vortex fluids, and polarization occurs in the relaxation-like manner. Taking the (velocity V_{ac} dependent) quantity τ we are in position to explain experimental results [1].

[1] A. Penzev, Y. Yasuta, and M. Kubota, Phys. Rev. Lett. 101, 065301 (2008).
[2] S. Nemirovskii, N. Shimizu, Y. Yasuta, and M. Kubota, arXiv: 0907.0330v3(2009).

e-mail: sergey Nemirovskii <nemir@itp.nsc.ru>

A5 Makoto Tsubota

Model of supersolids by the nonlocal Gross-Pitaevskii like equation

Makoto Tsubota, Hiromitsu Takeuchi, Kazuya Fujimoto
Department of Physics, Osaka City University

e-mail: Makoto Tsubota <tsubota@sci.osaka-cu.ac.jp>

A6 Anatoly B. Kuklov

Interconnection of mechanical and superfluid properties of solid He^4

A.B. Kuklov (CUNY, USA)

in collaboration with D. Aleinikava, E. Dedits, L. Pollet, N.V. Prokof’ev, G. Soyler, D. Schmeltzer and B.V. Svistunov.

First principle Monte Carlo simulations of a perfect crystal of hcp He4 have clearly excluded Andreev-Lifshits-Thouless-Chester type of supersolid and provided clear cut evidence that perfect hcp He4 is an insulator. Simulations of the topological structural defects – dislocations, grain boundaries, hcp-fcc faults and domain lines on the fault planes – have revealed that some dislocations and grain boundaries can support low-D superflow. Given that dislocations and grain boundaries are also primary carriers of crystal plasticity, the key question becomes: “Should we anticipate emergence of a new physics from combining two relatively well known phenomena – low-D superfluidity and mobility of the topological defects?” (cf. “Quantum Metallurgy”, A. Dorsey). I will discuss such an emergent effect -- ***superclimb of dislocations*** **and** ***giant isochoric compressibility*** [1]. It turns out that low-T non-conservative mobility (climb) of edge dislocations is, on one hand, controlled by the superflow and, on the other, affects dramatically properties of the supercurrents by changing their dispersion law from sound-like to quadratic. This requires reconsidering properties of the Shevchenko state [2] of a network of superfluid dislocations (cf. “Vortex Fluid”, by P.W. Anderson) by including the network plastic dynamics and its feedback on the superflow.

I will also present results of full quantum-thermal model studies of a single dislocation in the Peierls potential and in the presence of pinning centers (He^3 impurities). Such dislocation exhibits crossover to quantum smooth state leading to low-T hardening of shear modulus as observed by Day and Beamish [3]. Finite stresses reduce the hardening effect by generating dislocation kinks which promote dislocation decoupling from crystal lattice. This effect is inherently hysteretic even if no He^3 were present. Hysteresis is found to vanish above some temperature given by 0.25 - 0.3 of kink-antikink pair energy.

[1] Ş. G. Söyler, A. B. Kuklov, L. Pollet, N. V. Prokof’ev, and B. V. Svistunov, Phys. Rev. Lett. **103**, 175301 (2009);
[2] S. I. Shevchenko, Sov. J. Low Temp. Phys. 14, 553 (1988);
[3] J. Day and J. Beamish, Nature **450**, 853 (2007)

e-mail: Anatoly Kuklov <Anatoly.Kuklov@csi.cuny.edu>

A7 Shuji Harada

A Possible Quantum Phenomenon of Hydrogen in Pd-H System ?

T. Donuma[1], H. Araki[2], T. Kakuda[3], R. Nakatsuji[3], S. Harada[4], and M. Kubota[3]

1)Graduate School, Niigata Univ., 2)Nagaoka National College of Technology,
3)Institute for Solid State Physics, University of Tokyo, 4)Faculty of Engineering, Niigata University

Hydrogen atoms in a palladium metal lattice are known to be unique among other Metal-hydrogen(MH) systems[1]. They dissolve at densities up to one hydrogen atom per Pd ion, which provides higher atomic H density than in solid H_2. They are known to have a large diffusion coefficient due to quantum tunneling. At low temperatures and when the density x of H is increased, we may expect macroscopic quantum phenomena because of possible overlap of hydrogen wave functions and the Bose statistics of atomic H. To investigate experimentally the phase diagram of hydrogen in palladium, which is known to show phase boundaries at the lowest temperatures in the $x - T$ diagram among all known MH_x systems, specific heat measurements have been performed for Pd-H_x with x up to high hydrogen concentration specimens[2]. We have, in addition, been performing torsional oscillator (TO) experiments, which are a well-established, powerful method to investigate superfluidity and quantum vortices of liquid helium as well as dislocation dynamics in various solids, in order to study the atomic hydrogen dynamics in the PdH_x system. Our TO experiments have shown a resonance frequency shift and a Q value change for Pd-H_x, $0.16 =< x =< 0.75$ specimens around the transition temperature of 50 K obtained by the specific heat measurement[2]. We discuss possible occurrence of quantum phenomenon.

[1] Y. Fukai, "The Metal-Hydrogen System", Springer Verlag (2005).
[2] H. Araki, M. Nakamura, S. Harada, T. Obata, N. Mikhin, V. Syvokon and M.Kubota, J. Low Temp. Phys., Vol.134, pp.1145 - 1151(2004); H. Araki, S. Harada, and M. Kubota, J. Phys. Chem. Solids 66 pp. 1490-1492 (2005); H. Araki, S. Harada, M. Fukuda, V. Syvokon M. Kubota, Physica B, Vol.284-288, 1255 -1256 (2000).

e-mail: Shuji HARADA <sharada@eng.niigata-u.ac.jp>

B1 Osamu Yamamuro

Experimental studies on glass transitions and dynamics of supercooled liquids

Osamu Yamamuro
Institute for Solid State Physics (ISSP), University of Tokyo, Kashiwanoha 5-1-5, Kashiwa, 277-8581, Japan

The glass transition has been one of the most important topics of condensed matter physics for a long time. Configurational motions of liquids, which are called "α process" and usually associated with translation and rotation of liquid particles, become slower as decreasing temperature. The relaxation time of the α process tends to diverge at T_0 which is called "ideal glass transition temperature". The actual glass transition is a freezing phenomenon which occurs when the α relaxation time reaches the experimental time scale (ca. 100 s corresponding to viscosity of 10^{13} Poise) in a supercooled state. Fig. 1 shows the heat capacity of a typical molecular glass 1-butene. The heat capacity changes abruptly at T_g (= 60 K) since the configurational motions are frozen-in below T_g.

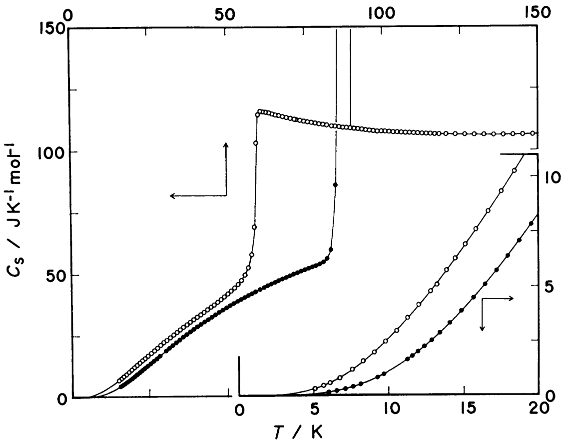


Fig.1. Heat capacity of glassy 1-butene

There are another relaxations called "β process" as shown in Fig. 2. The slow β process appears and the fast β process disappears below the critical temperature T_c which is usually 1.2-1.3 times of T_g. It is also know that vibrational excitations called "boson peak" exist below T_c. The large heat capacity difference between the glass and crystal in Fig.1 is due to this excitation. In spite of a number of experimental and theoretical studies, the mechanism of the glass transition and the origins of the β process and boson peak have not been clarified yet.

In the workshop, I will talk about the basic features and interests of the glass transition as mentioned above. And I will also show some of our calorimetric and neutron scattering studies on the glass transitions and boson peaks of simple molecular glasses.

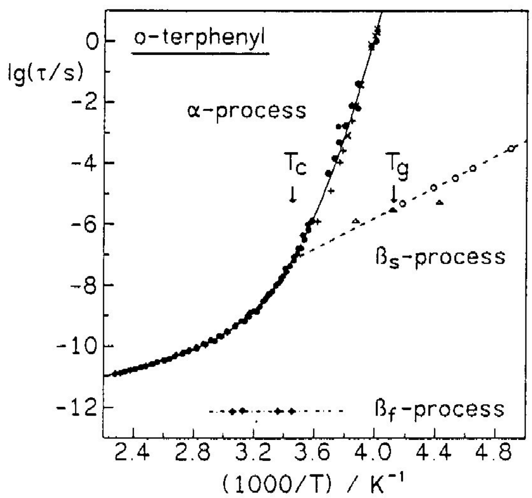


Fig.2. Relaxation times of o-terphenyl

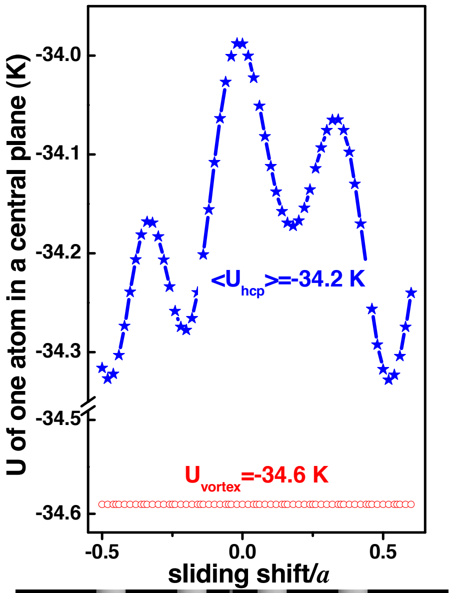
e-mail: yamamuro@issp.u-tokyo.ac.jp

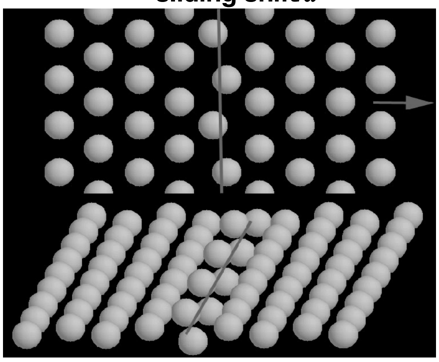
B2 Nina Krainyukova

Delocalization via Sliding and 2D Vorticity in Solid ^{4}He

Nina Krainyukova
Verkin Institute for Low Temperature Physics & Engineering NASU, 47 Lenin ave., Kharkov 61103, Ukraine

Since the first experimental observation of the phenomenon of ‘supersolidity’ [1], which was confirmed later by other experimental groups [2-5], numerous mechanisms of delocalization were proposed [6]. Recently we have suggested one more possible scheme [7] of delocalization, in which two crystal parts slide with respect to each other along the basal plane of the hcp and possibly intermediate phases. Assuming atoms to be located at lattice sites we calculated the potential profiles shown in the upper figure (the curve with stars) for the hcp crystal. The characteristic roughness was found to be much lower as compared with shifts of a single atom and evidences that such a mechanism may be certainly operative above 0.3-0.5 K that correlates with an experimental observation of the energy dissipation in the torsional oscillation experiments [4] in particular at such temperatures. But apparently more interesting would be prediction of dissipation free mechanisms or at least those which require energies below 0.1 K. In quest of such schemes we analyzed in more details possible atomic trajectories in the sliding processes. We have found that when atoms are not located at sites but circulate around some axes in the hcp basal planes (see the lower figure) they may move (while sliding) along trajectories with an equal potential and practically with no dissipation (see the lower line with circles in the upper figure). According to our calculations the characteristic radius of such a circulation can be ~0.65 Å. At lowering temperatures circulations have a tendency to alignments along a basal plane forming the 2D vortex system. Such nanosized vortices have empty cores and therefore may not destroy supersolidity (if it appears) and possibly are relevant to this phenomenon as it was recently discussed [8, 9]. Allowing for the quantization condition $\oint v dl = h/m$ typical of vortices the kinetic energy determined by the atomic velocity v is about 50-60mK. Vortices can appear and are well stabilized at T<0.6 K (see the upper figure). Besides they may be responsible for a linear contribution in the specific heat measurements [10] because they are linear formations (similarly to linear defects).





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e-mail: ninakrai@yahoo.com

B3 Masaru Suzuki

Slippage and Superfluidity of Helium Films Adsorbed on Graphite

Masaru Suzuki
Department of Applied Physics and Chemistry, University of Electro-Communications
1-5-1 Chofugaoka, Chofu, Tokyo 182-8585.

We have carried out 5 MHz AT-cut quartz-crystal microbalance (QCM) experiments for ^{4}He films adsorbed on graphite in order to study the slippage and superfluidity. The following properties of the slippage and the frictional force of ^{4}He films on graphite have been revealed:

(1) At two-atom and three-atom thick films, the frictional force of the boundary of the first and second atomic layers is much smaller than that of the boundary between the film and the substrate.

(2) At two-atom and three-atom thick films, the frictional force remains metastable at low temperatures after switching of the driving force.

(3)At four-atom thick films, the solid atomic layer underneath the superfluid layer stops the slippage on the oscillating substrate.

These observations can be explained by the motion of edge dislocations between the first and second atomic layers.

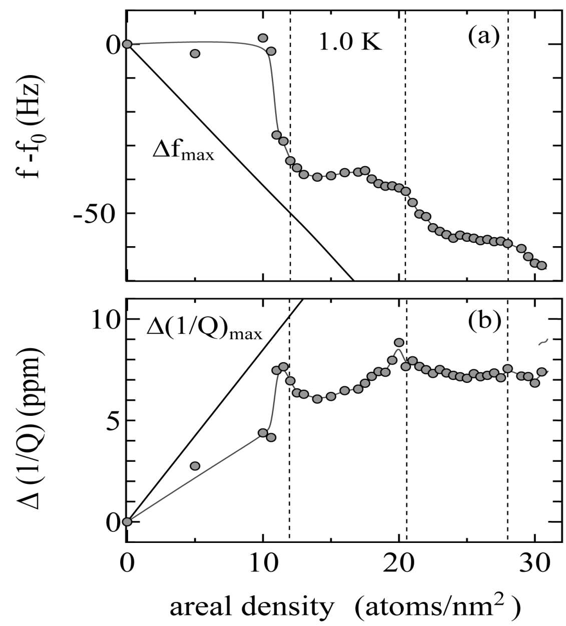

Fig. 1. Areal density dependence of the changes in f and Q^{-1}.

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e-mail: suzuki@phys.uec.ac.jp

B4 Tomoki Minoguchi

New dynamics of He-4 films on graphite
—Superfluid dynamics coupled with solid bilayer—

Tomoki Minoguchi
Institute of Physics, University of Tokyo, Komaba 3-8-1, Meguro, Tokyo 153-8902, Japan
E-mail: mino@phys.c.u-tokyo.ac.jp

Dislocation in solid He-4 attracts much attention in the context of supersolidity. Supersolidity-like behavior is reported also in a two dimensional case, the solid thin layer of He-4 adsorbed on graphite surface [1]. In contrast to it, it has been found in experiment by Hosomi et. al. that the solid thin layer 'sticks' to the graphite surface in the presence of superfluid overlayer, while the solid layer decouples from the substrate if the overlayer is normal fluid[2]. In this talk, I will introduce a model consisting from a superfluid overlayer and a solid layer containing mobile component (typically edge dislocation) [3]. Due to the smoothness of the substrate, the edge dislocation has dynamics. The dislocation motion can drag the normal fluid component in the superfluid overlayer and hence causes temperature gradient in the superfluid overlayer. It costs energy in proportion to the superfluid density, and the motion is suppressed. The other interesting possibilities containing crystallization wave [2] will be also suggested.

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e-mail: <mino@phys.c.u-tokyo.ac.jp>

B5 Keiya Shirahama

Supersolid Behaviors in Thin "Rods" and "Films" of Solid ^{4}He in a Nanoporous Glass

Keiya Shirahama
Department of Physics, Keio University, Yokohama 223-8522

Liquid and solid ^{4}He are the best-known examples of strongly correlated Bose system. The confinement of ^{4}He to nanoporous structure enables us to control the correlation, dimensionality and topology, and introduce disorder. ^{4}He in nanoporous media may therefore produce novel bosonic ground states: Supersolid state is one of them. Here we report on the observation of supersolid-like behaviors in (1) confined ^{4}He solid in a nanoporous Gelsil glass (pore size: 2.5 nm) and (2) thin solid ^{4}He films adsorbed on the same porous glass. A torsional oscillator exhibits mass decoupling with dissipation in the both cases. In the former case, the supersolid responses are quantitatively similar to those observed in bulk solid ^{4}He; i.e. no supersolid size effects were observed. This strongly suggests that the characteristic length scale for putative supersolidity is much smaller than the pore size. In the latter experiment, the temperature at which the supersolid-like behaviors are observed strongly depends on the solid film thickness. The overall features are attributed to a quantum critical phenomenon around a critical film thickness over which true liquid film superfluidity is observed.

e-mail: <keiya@phys.keio.ac.jp>

B6 Yuichi Okuda

Thermal and quantum crystallizations of ^{4}He in aerogel

YUICHI OKUDA
Tokyo Institute of Technology

The way of the crystallizationof ^{4}He in aerogel was known to show a dynamical phase transition due to the competition between thermal fluctuation and disorder: crystals grow via creep at high temperatures and via avalanche at low temperatures (Phys. Rev. Lett. 101, 175703 (2008)). Here we report the growth velocity and the crystallization pressure of 4He in both regions. In the creep region, crystal growth is faster at higher temperature and becomes slower with cooling. This is consistent with the expectation that crystal growth is via a thermally activated interface motion in the disordered media in the creep region. This temperature dependence is opposite to the bulk crystal growth. Growth velocity is the lowest at the transition temperature. In the avalanche region, it slightly increases with cooling and saturates at lower temperature. This temperature independent growth is presumably the result of the macroscopic quantum tunneling through the disorder. The crystallization pressure in aerogel is not just like a shift of the bulk crystallization pressure but has a maximum at the transition temperature.

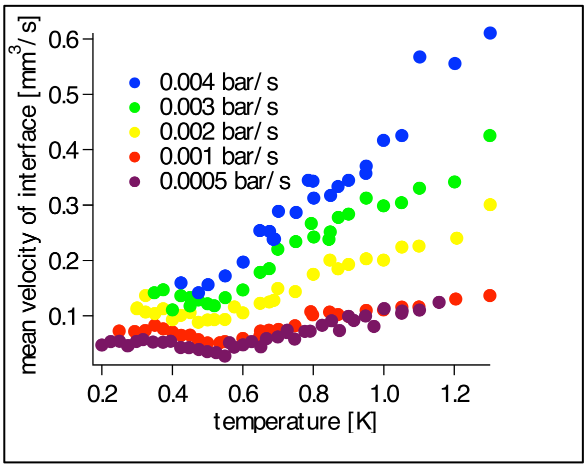

Fig.1 Mean growth velocity of the crystal in the 96 % aerogel plotted against temperature. The growth velocity shows the minimum at the temperature of the dynamical transition.

e- mail: Yuichi Okuda <okuda@ap.titech.ac.jp>

B7 Eunseong Kim

Can supersolidity be suppressed in stiffened solid ^{4}He?

D. Y. Kim, H. Choi, W. Choi, S. Kwon, and E. Kim

Center for Supersolid & Quantum Matter Research and Department of Physics, KAIST, Daejeon 305-701, Korea.

H. C. Kim

National Fusion Research Institute (NFRI), Daejeon 305-333, Korea.

The observation of non-classical rotational inertia (NCRI) in solid helium has drawn attention because it was possibly the first experimental evidence of supersolid, a crystalline solid exhibiting superfluidity. Recently, shear modulus, μ, revealed anomalous behaviours that showed striking resemblance in the temperature, frequency, and ^{3}He concentration dependence to those of NCRI. The anomaly in μ can be understood with immobilization of dislocations by ^{3}He impurities without involving superfluidity. Extensive investigation on this phenomenon has shown that the anomaly in μ appears in hcp helium crystals irrespective of quantum statistics, while NCRI is found only in a bosonic solid. Here we report the first simultaneous measurement of shear modulus and NCRI in solid helium to elucidate the fundamental connection between them. Both emerge at remarkably similar temperatures, while no quantitative agreement between the increase of the shear modulus and the magnitude of NCRI is found. The most compelling observation is that NCRI can be reduced at very low stress fields in which ^{3}He impurities are still bound to dislocation lines, indicating that NCRI is suppressed by different excitations from dislocation stiffening.

e-mail: Eunseong Kim <eunseong@kaist.edu>

B8

Discussion and Summary

What Have we learned?

Bulk hcp He, what are the specifics?
Same physics as in restricted geometry?
Slippage in the film, also in the bulk?
Evidencies of quantized vortices and vortex state?
Hardening and supersolid?
Do we expect some other supersolid state in other systems?
What is the connection to a glass transition, if any?

List of Participants

Speakers

No.	Name	Affiliation	E-mail Address
1	Shuji Harada	Niigata University, Niigata	sharada@eng.niigata-u.ac.jp
2	Izumi Iwasa	Fuji Xerox Co., Ltd.	iwasa@mva.biglobe.ne.jp
3	Eunseong Kim	KAIST, Daejeon 305-701 Korea	eunseong@kaist.edu
4	Nina Krainyukova	Institute for Low Temp.Physics & Engineering NASU, Kharkov	ninakrai@yahoo.com
5	Minoru Kubota	ISSP, Univ. of Tokyo, Kashiwa	kubota@issp.u-tokyo.ac.jp
6	Anatoly Kuklov	City University of New York, USA	kuklov@mail.csi.cuny.edu
7	Tomoki Minoguchi	The University of Tokyo	mino@phys.c.u-tokyo.ac.jp
8	Sergey Nemirovskii	Insititute for Thermo Physics, RAS, Novosibirsk, Russia	nemir@itp.nsc.ru
9	Yuichi Okuda	Tokyo Instit. of Technology, Tokyo	okuda@ap.titech.ac.jp
10	Keiya Shirahama	Keio University, Yokohama	keiya@phys.keio.ac.jp
11	Masaru Suzuki	Univ. of Electro-communications, Tokyo	m-suzuki@pc.uec.ac.jp
12	Ryo Toda	Kyoto University, Kyoto	rftoda@scphys.kyoto-u.ac.jp
13	Makoto Tsubota	Osaka City University, Osaka	tsubota@sci.osaka-cu.ac.jp
14	Osamu Yamamuro	ISSP, Univ. of Tokyo, Kashiwa	yamamuro@issp.u-tokyo.ac.jp

Registered Participants

No.	Name	Affiliation	E-mail Address
1	T. Donuma	Niigata University	f07b502h@mail.cc.niigata-u.ac.jp
2	T. Kawae	Kyushu University	kawaetap@mbox.nc.kyushu-u.ac.jp
3	A. Kitamura	Niigata University	f09b121h@mail.cc.niigata-u.ac.jp
4	M. Kobayashi	The University of Tokyo	michikaz@cat.phys.s.u-tokyo.ac.jp
5	M. Kohmoto	ISSP, University of Tokyo	kohmoto@issp.u-tokyo.ac.jp
6	H. Noguchi	ISSP, University of Tokyo	noguchi@issp.u-tokyo.ac.jp
7	R. Nomura	Tokyo Institute of Technology	nomura@ap.titech.ac.jp
8	K. Okamoto	Tokyo Institute of Technology	kokamoto@phys.titech.ac.jp
9	Y. Sasaki	Kyoto University	sasaki@scphys.kyoto-u.ac.jp
10	Y. Sasaki	Graduate School of Frontier Sciences, The University of Tokyo	ycsasaki@k.u-tokyo.ac.jp
11	T. Shigematsu	Sasebo National College of Technology	shige@post.cc.sasebo.ac.jp
12	T. Suemoto	ISSP, University of Tokyo	suemoto@issp.u-tokyo.ac.jp
13	H. Suzuki	Kanazawa University	hsuzuki@cphys.s.kanazawa-u.ac.jp
14	M. Uwaha	Nagoya University	uwaha@nagoya-u.jp
15	S. Watabe	The University of Tokyo	watabe@vortex.c.u-tokyo.ac.jp
16	M. Yagi	The University of Tokyo	m.yagi@issp.u-tokyo.ac.jp

Other Participants

No.	Name	Affiliation	E-mail Address
1	C. Ganguli	ISSP, University of Tokyo	
2	Y. Karaki	ISSP, University of Tokyo	
3	Y. Katoh	The University of Tokyo	
4	H. Komori	ISSP, University of Tokyo	
5	T. Sato	ISSP, University of Tokyo	
6	T. Suzuki	ISSP, University of Tokyo	
7	H. Wu	ISSP, University of Tokyo	