P-1 Quantum Fluctuations and Superconductivity in Valence Transition System

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Quantum criticality and electronic instability emerging when first-order-transition temperatures are suppressed to absolute zero has attracted much attention. Valence transition provides a prototype of a metal-to-metal first-order transition with a critical end point, which is an isostructural transition known to occur in Ce metal as γ-α transition. When the critical end point approaches zero temperature and enters the quantum critical regime, enhanced valence fluctuations coupled with Fermi-surface instability are considered to play a crucial role for electronic instability.

To get insight into the nature of the critical end point in the quantum degeneracy regime, we have studied the ground-state properties of a minimal model for the valence transition [1,2]. We have found that the phase separation accompanied by the first-order valence transition is suppressed by quantum fluctuations and superconducting correlations grow near the quantum critical point. The origin of the superconductivity is ascribed to enhanced valence fluctuations coexisting with the development of coherent motion of electrons. The underlying mechanism of these novel phenomena as well as the quantum critical nature of the valence transition will be discussed.

[1] S. Watanabe, M. Imada and K. Miyake, J. Phys. Soc. Jpn. **75** (2006) 043710.
[2] S. Watanabe, M. Imada and K. Miyake, in preparation.

P-2 Singularities of Charge Fluctuations and Conductivity around Tricritical Point

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Tricritical point in charge-order systems and its criticality are studied for a microscopic model by using the exchange Monte Carlo method in the classical limit as well as by using the Hartree-Fock approximation for the itinerant electron model[1]. We study the extended Hubbard model and show that the tricritical point emerges as an endpoint of the first-order transition line between the disordered phase and the charge-ordered phase at finite temperatures. Strong divergences of several fluctuations at zero wavenumber are found and analyzed around the tricritical point. Especially, the uniform charge susceptibility and the susceptibility of the double occupancy are shown to diverge with power law. The singularity of conductivity around the tricritical point is also clarified. We show that the singularity of the conductivity σ has the form, which is given as $|\sigma-\sigma_c| \sim |T-T_c|^p$ ($A\log|T-T_c|+B$), where T is temperature and σ_c (T_c) represents the critical conductivity (temperature) and A and B are constants, respectively. The results are compared with available experimental results of organic conductor $(DI\text{-}DCNQI)_2Ag$[2].

[1] T. Misawa, Y. Yamaji, and M. Imada: J. Phys. Soc. Jpn. **75** (2006) 064705
[2] T. Itou, K. Kanoda, K. Murata, T. Matsumoto, K. Hirai, and T. Takahashi: Phys. Rev. Lett. **93** (2004) 216408

P-3 Finite temperature Mott transition in Hubbard model on anisotropic triangular lattice

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Motivated by a novel spin liquid behavior and metal-insulator transitions (MIT) [1] observed in triangular lattice organic materials [2,3], we studied Mott transition in the Hubbard model on the anisotropic triangular lattice using the cellular dynamical mean field theory [4]. We obtained the finite-temperature (T) phase diagram for MIT, where the T-dependence of critical interaction strength is qualitatively different from well-known theory in infinite dimensions [5] but similar to the reentrant behavior experimentally observed in organic materials such as κ-$(ET)_2Cu[N(CN)_2]Cl$ [3]. We also investigated the momentum dependence of the single particle spectra, which clarified the essential difference between the insulator at high-T and that in low-T.

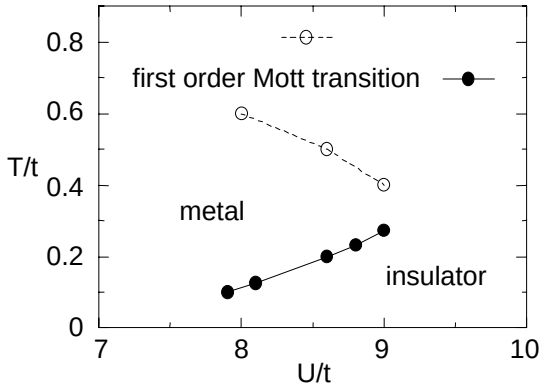

FIG: Phase diagram of MIT for t'/t=0.8.

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[3] F. Kagawa et al., Phys. Rev. B **69**, 064511 (2004).
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P-4 Heat Capacity of ^{3}He Solid Films on Graphite in Magnetic Fields

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A ^{3}He solid film adsorbed on a graphite surface is one of the most ideal two-dimensional quantum spin systems. Its magnetic properties are thought to be results of competition of multiple spin exchange (MSE) interactions, and the competition is stronger than in bcc solid ^{3}He. I present preliminary results of heat-capacity measurements of ^{3}He solid films in magnetic fields up to several hundreds Oe. In the first adsorbed atomic layer, results of heat-capacity measurements show large shifts to higher temperature with increasing magnetic field. While in the second layer, such a large shift of heat capacity has not been observed, but obvious and complicated changes were observed. Heat capacity differences between in a magnetic field of 300 Oe and in a zero magnetic field are shown in FIG. 1 for several areal densities. These results should indicate that some frustrations preventing the short range ordering of the spins, or the magnitudes of MSE interactions are strongly affected by the magnetic field.

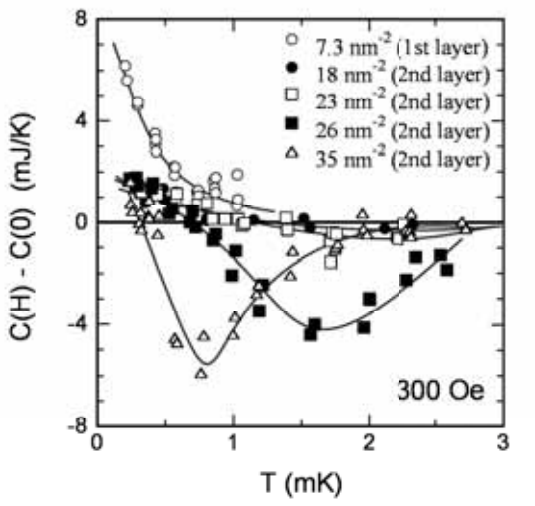

FIG.1: Heat capacity differences between in a magnetic field of 300 Oe and in a zero magnetic field. Solid lines are guides for the eye.

P-5

Heat Transfer between ^{3}He Solid Films and Graphite in Magnetic Fields

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It is known that ^{3}He films adsorbed on graphite substrates can be cooled down at least below 100 μK following graphite substrates. However, the heat transfer mechanism between ^{3}He films and graphite substrates is not clearly understood. The results of my previous thermal conductance measurements reveal that heat is transferred only by local spots between the ^{3}He films and graphite substrates. Within the ^{3}He films, heat is transferred by some magnetic mechanism. The magnetic Kapitza conductance between ^{3}He and magnetic impurities in graphite substrates is suggested to be this heat transfer mechanism between ^{3}He films and graphite substrates. I report the results of thermal conductance measurements between second-layer ^{3}He solid films and a graphite substrate in magnetic fields up to 300 Oe. The thermal conductance is strongly influenced by the magnetic field in both the first and second adsorbed atomic layers as shown in FIG. 1. According to the observations, the heat transfer mechanisms will be discussed.

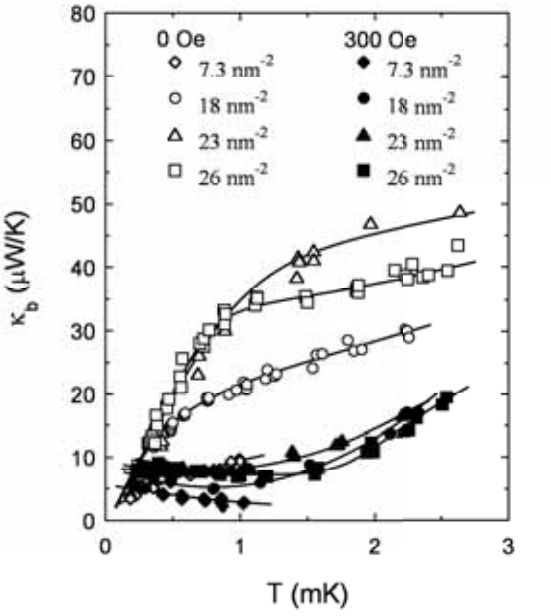

FIG.1: Measured thermal conductance between solid ^{3}He films and graphite substrate in the magnetic field of 0 and 300 Oe. Solid lines are guides for the eye.

P-6

Pronounced non-Fermi-liquid behavior of a new Yb based heavy fermion system

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Extensive studies have been made on quantum criticality in heavy fermion systems because of the possible breakdown of Fermi liquid state and novel phase formation near a qunatum critical point. Ideal for such studies is a clean material that exhibits non-Fermi-liquid behavior under ambient pressure and field, but few has been known so far. In comparison with Ce compounds, Yb based one *f*-hole systems have not been well studied because of difficulty of sample preparations. Here, we report the observation of pronounced non-Fermi-liquid behavior at $B = 0$ and $P = 0$ in a new layered Yb based compound. The system is clean with the residual resistivity ratio (RRR) more than 200 and mean free path ~ 0.5 μm. Both specific heat and dc-susceptibility shows strong divergence toward the lowest temperature 80 mK, suggesting that quasi-particle weight is zero at $T \rightarrow 0$ limit. This work is the collaboration with K. Kuga, Y. Machida, S. Yonezawa, Y. Maeno, Z. Fisk, T. Sakakibara, T. Tayama, R. Macaluso, and J. Chan

P-7 Phase Transition in the ν = 1/3 Bilayer Fractional Quantum Hall State

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Fractional quantum Hall state (FQHS) at the Landau level filling factor ν = 1/3 is interpreted as a ν = 1 integer quantum Hall state (IQHS) of composite fermions; a composite fermion consists of one electron and two flux quanta. The ν = 1 IQHS in a bilayer system is stabilized by the interlayer phase coherence of two-dimensional electron. In this state, the layer degree of freedom (pseudospin) plays an essential role and the properties of pseudospins are well illustrated by the commensurate-incommensurate quantum phase transition. We investigate the *bilayer* ν = 1/3 FQHS in the point of view if it has an interlayer phase coherence as well as the ν = 1 IQHS, and if it has, what is the difference between the bilayer ν = 1/3 FQHS and the bilayer ν = 1 IQHS.

We study the magnetotransport properties of the bilayer ν = 1/3 FQHS using a GaAs/AlGaAs double-quantum-well sample with the tunneling energy 11 K for various total electron densities, density differences between two layers and in-plane magnetic fields. The magnetoresistance measurements as a function of the density difference indicate that the bilayer ν = 1/3 FQHS is stabilized by the interlayer interactions as well as the bilayer ν = 1 IQHS. The activation energy measurements as a function of the in-plane magnetic field reveal that there exists only commensurate phase in the bilayer ν = 1/3 FQHS in contrast to the occurrence of both commensurate and incommensurate phases in the ν = 1 IQHS. This fact indicates that interactions between composite fermions are weak in the bilayer ν = 1/3 FQHS.

P-8
Domain Structure at the Spin Transition Point of ν=2/3 Quantum Hall State

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Nuclear spin system attracts renewed attention in light of spintronics or quantum information processing. Recently, nuclear spin polarization accompanied by hysteretic transport is observed at the spin transition point of fractional quantum Hall (QH) states. The occurrence of the nuclear polarization is explained by the following scenario. At the spin transition point, two QH states with different spin polarization are degenerate and an electronic domain structure is formed. When an electron passes across the domain wall, electron spin flip-flop scatters nuclear spins, producing current-induced nuclear polarization. However, details of the domain structure are not completely understood yet.

In this work, we study the domain structure in tilted magnetic field and elucidate that it has an anisotropic structure against the direction of the in-plane field $B_{||}$. We measured magnetoresistance R_{xx} as a function of magnetic field around the spin transition point at the Landau level filling factor ν=2/3 by changing the angle between the current I and $B_{||}$. When I is orthogonal to $B_{||}$, a strong hysteresis emerges in R_{xx}. In contrast, when I is parallel to $B_{||}$, the hysteresis disappears.

Because hysteresis is caused by the current-induced nuclear polarization, the result indicates that more electrons pass across domain walls when the current is driven perpendicular to $B_{||}$. Thus, we suggest that the domain walls align along to $B_{||}$ and the nuclear polarization can be manipulated by changing the direction of $B_{||}$.

P-9

Hysteresis in the Bilayer Quantum Hall System in Tilted Magnetic Field

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In quantum Hall (QH) systems, hysteretic transport induced by electron-electron interactions or background potential fluctuations has been observed. These observations reveal fascinating phenomena, such as the QH ferromagnetism and electron-nuclear spin interactions. On the other hand, bilayer systems consisting of two closely spaced two-dimensional electron systems exhibit rich phenomena due to the layer degree of freedom. For instance, in the bilayer QH state at ν=3, the transition from a strongly correlated incompressible state at lower in-plane magnetic fields $B_{\|}$ to a weakly correlated compressible state at higher $B_{\|}$ occurs because the layer tunneling is suppressed by $B_{\|}$.

In this work, we found that new hysteretic transport occurs in the bilayer ν=3 as large $B_{\|}$ is applied. The sample used in the experiment consists of two GaAs quantum wells with the tunneling energy gap 11K. Electron density of each layer was independently controlled by the front and back gates. We measured magnetoresistance R_{xx} as a function of the magnetic field perpendicular to the two-dimensional plane for various $B_{\|}$. When $B_{\|}$ is small, the QH state is well developed at ν=3. In contrast, when large $B_{\|}$ is applied, the ν=3 QH state collapses and the hysteretic transport occurs in R_{xx}. In the workshop, we will argue the origin of the hysteretic transport from the current and temperature dependence of R_{xx}.

P-10

Quantum Criticalities induced by Changes of Fermi Surface Topology in Itinerant Electron Metamagnets

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We present a mean-field theory on criticalities around quantum critical endpoints of itinerant electron metamagnetism driven by changes in Fermi surface topology, so called Lifshitz transitions[1]. At the endpoint, the quantum criticalities are different from those of the Ising criticality, which are expected by the Moriya-Hertz-Millis theory [2]. The singular part of the magnetization m_s around the endpoint is given as a function of a magnetic field h as, $m_s \sim C_+ |h - h_c|^{p+}$, for $h > h_c$, and $m_s \sim C_- |h - h_c|^{p-}$, for $h < h_c$, where h_c is a critical amplitude of the magnetic field and $C_\pm$ are constants. The powers $p_\pm$ are determined by the type of topological changes in Fermi surface and the dimensionality of the electron systems. In general, m_s shows an asymmetric behavior, $p_+ \neq p_-$, which comes from the different topology of Fermi surfaces in the both sides of the critical point. The quantum criticalities induced by the Fermi surface topology also appear in other itinerant electron systems, where an increasing amplitude of a preexisting long range order, instead of the uniform magnetization, drives the Lifshitz transitions [3].

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P-11 Mott transition and charge ordering in molecular conductors

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We report our recent theoretical results on the metal-insulator transition (MIT) and related phenomena in molecular conductors. MIT is widely observed in both quasi 1D and quasi 2D materials, and its origin is ascribed to strong electronic correlations: In the effectively half-filled systems, MIT is called the Mott transition and its driving force is the on-site Coulomb repulsion, while in the effectively quarter-filled systems, the off-site Coulomb interaction plays a role to establish charge ordering as an origin of MIT. In some cases, electron-phonon couplings and/or lattice structure are also important to understand the nature of MIT. Recent experimental studies by chemical substitutions and the external pressure have revealed systematic changes of the electronic properties, and open possibility of comprehensive understanding of these phenomena.

In this contribution, we focus on the following issues:

- Mott transition and geometrical frustration in quasi 2D compounds, κ-(BEDT-TTF)$_2X$, by the exact diagonalization of the Hubbard model on an anisotropic triangular lattice
- Charge ordering and bond dimerization/tetramarization in quasi 1D compounds such as DCNQI$_2X$ and TM$_2X$, in terms of the quantum transfer matrix method with interchain mean-field approximation for the extended Hubbard model including electron-lattice coupling
- Charge ordering and its fluctuations in quasi 2D compounds, θ-(BEDT-TTF)$_2X$, by the random-phase approximation and the Hartree-Fock approximation for the extended Hubbard model including electron-phonon couplings

This presentation is based on works in collaboration with A. Furusaki, T. Kato, T. Koretsune, H. Seo, and M. Udagawa.

P-12
Low Temperature Transport and Thermodynamic properties of $CeTe_3$

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$CeTe_3$ belongs to the family of quasi-two dimensional compounds RTe_3 (where R = Y, La-Sm, Gd-Tm) [1,2]. The crystal structure is weakly orthorhombic. First-principles band-structure calculations reveal that the Fermi surface consists of inner and outer square sheets, large regions of which are nested by a single incommensurate wave-vector corresponding to the observed lattice-modulation [3]. Because of the characteristic quasi-two-dimensional nature of the Te sheet, the charge-density-wave (CDW) is formed with an extremely large gap of the order of 100 meV [4-6]. Despite the extensive studies on the CDW in recent years, remarkably little is known about low-temperature properties of $CeTe_3$. We measured the low temperature resistivity and specific heat of $CeTe_3$ with single crystals grown from Te-fluxes. We will discuss low temperature transport and thermodynamic properties of $CeTe_3$.

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[6] C. Malliakas *et al*., J. Am. Chem. Soc. **127** (2005) 6510.

P-13 Quantum Phase Transitions in the Periodic Anderson Model

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Strongly correlated electron systems with orbital degeneracy have attracted considerable interest. Typical examples are the transition metal oxides LiV_2O_4 [1] and $Ca_{1.8}Sr_{0.2}RuO_4$ [2], where heavy fermion behavior is realized due to the degeneracy of t_{2g}-orbitals in combination with the crystal structure. Furthermore, it was recently suggested that t_{2g} electrons play distinct roles in compounds, where localized and itinerant electrons in the same subshell hybridize with each other to stabilize the heavy electrons [3, 4]. This may be related to the concept of the orbital-selective Mott transition [5], which stimulates further theoretical investigations on multiorbital systems.

To clarify how the heavy fermion behavior is realized in these compounds, we investigate the extended periodic Anderson model [3]. By combining the dynamical mean field theory with exact diagonalization and the numerical renormalization group, we discuss the ground state properties in the particle-hole symmetric system. We clarify that the Hund coupling between degenerate orbitals plays an important role to realize the quantum phase transition between the Kondo insulating phase and the Mott insulating phase. We also address how the heavy fermion behavior is realized in the doped case.

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P-14 Canted antiferromagnetism induced by chemical pressure in Yb-based compound

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Extensive studies have been made on quantum criticality in heavy fermion systems because of the possible breakdown of Fermi liquid state and the emergence of a novel phase near a qunatum critical point. Generally in Yb-based heavy fermion systems, magnetic morment is expected to be stabilized under pressure. For example in $YbInCu_4$, a magnetically ordered state becomes stable above $P_c = 2.4$ GPa [1]. Here, we present our recent work on a chemical pressure effect of an Yb-based compound. We found that a nonmagnetic heavy fermion state transits into a weak ferromagnetic state as a function of chemical substitution. The magnetic ordering temperature reaches up to $T_N = 8$ K. Since T_N is suppressed by applying a magnetic field, this magnetic order is most probably associated with canted antiferromagnetism.

[1] T.Mito *et al*., Phys. Rev. B **67**, 224409 (2003)

P-15 Microwave Excitation and Heating of Surface-State Electrons on Liquid He^3

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Spectroscopic studies of the surface-state electrons (SSEs) on liquid helium have been carried for more then two decades. The recent interest to such studies has been caused by the theoretical proposal [1] that the SSEs on the two lowest quantum states could be used as electronic quibits controlled by the microwave (MW) field. In our experiment, we combine the MW excitation and the dc-resistivity measurements done with the SSEs on liquid He^3. The observed increase of the electron resistivity at the MW absorption resonance suggests that the excitation is accompanied by the strong heating of the SSEs. We propose a theoretical model which describes the heating mechanism and take into account the thermal population of higher excited states. The calculated resistivity change is in good agreement with the experimental result. We conclude that the heating, which was ignored in all previous spectroscopic studies, is a very important factor for the adequate analysis of the MW absorption experiments.

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P-16 Coexisting charge fluctuations and their temperature dependence in organic conductors, θ-(BEDT-TTF)2MM'(SCN)4

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Recently, considerable attention has been focused on organic compound, θ-(BEDT-TTF)2MM'(SCN)4 . Here, M=Cs, Rb, Tl leads to a different dihedral angle φ between BEDT-TTF molecules (Fig.1). For larger φ(M=Rb and Tl), charge ordering is observed below ～200K. While for smaller φ(M=Cs), two diffuse X-ray spots suggest that short-range charge modulations with different wave vectors coexist, instead of the long-range orderings.

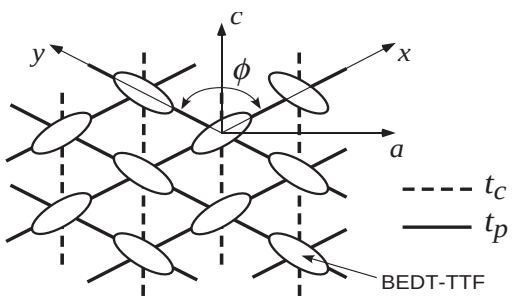

FIG.1: Schematic picture of BEDT-TTF conducting layer.

We have theoretically studied the origin of these phenomena by the random phase approximation for the extended Hubbard model on an anisotropic triangular lattice including electron-phonon couplings. The variation of dihedral angle φcan be taken into account as the anisotropy of the transfer integrals (t_c/t_p = 0.5, 0.4 and 0.1 for M=Tl, Rb and Cs, respectively. See Fig.1). We have successfully reproduced the experimental phase diagram: a stripe-type charge order occurs at some temperatures for larger t_c/t_p, while the charge order is suppressed for smaller t_c/t_p. Furthermore, we have obtained the coexisting charge fluctuations with different wave numbers near the critical region, where the transition temperature is suppressed down to the absolute zero.

In this contribution, we will discuss the temperature dependence of the coexisting charge fluctuations in comparison with the X-ray data. In particular, we will focus on the saturation of charge fluctuations as a function of temperature, and discuss its relation to transport properties. We will also show our results of the sensitivity of charge ordering patterns to the electron-phonon couplings.

P-17 Heat capacity measurements of two-dimensional ^{3}He doped with holes in high magnetic fields

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Monolayer ^{3}He adsorbed on a graphite surface is an ideal model system for strongly correlated two-dimensional (2D) Fermions. Recent heat capacity measurements showed a thermodynamic evidence for zero-point vacancies (holes) doped into the 4/7 Mott localized phase [1]. The hole doped Mott solid is characterized by the anomalous coexistence of a magnetic round peak near 1 mK and another which is associated with hole motion at few tens of mK. A spin-mass separation in 2D which is an analogue to the spin-charge separation in 1D interacting electrons and the phase separation in the momentum space (two fluid model [2]) are proposed as possible interpretations for these anomalies. To test these hypotheses, we start new heat capacity measurements in the temperature range above 7 mK in high magnetic fields up to 9 T. We observed, for a hole-doped sample, large enhancement of the lower temperature peak in magnetic fields. Relatively sharp anomaly was also observed near 10 mK in magnetic field of 8.6 T. These anomalous behaviors in magnetic fields will be discussed in detail.

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P-18
3D Ferromagnetic Ordering Realized in Quasi-1D Heisenberg Ferromagnet β-BBDTA·GaBr$_4$

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An organic magnet β-BBDTA·GaBr$_4$ has isotropic (Heisenberg) S = 1/2 spins of unpaired electrons in radical cations BBDTA$^+$. This has two kinds of one-dimensional (1D) chains. One is the antiferromagnetic chain with large interaction $2J_{1DAF}$ = −186 K whose magnetism is negligible below 10 K. The other is the ferromagnetic chain with $2J_{1DF}$ = 8 K. At T_C = 0.4 K, we observed a ferromagnetic long-range ordering induced by an inter-chain interaction between ferromagnetic chains. The magnetization and the magnetic field dependence of T_C suggest that the inter-chain interaction is ferromagnetic and it was estimated to be $2zJ_F$ = 0.29 K from the susceptibility. In FIG.1, the specific heats in several magnetic fields are compared with a mean-field calculation by using parameters obtained from the susceptibility. The calculation reproduced experimental results quantitatively, which indicates that β-BBDTA·GaBr$_4$ is a typical three-dimensional ordering system realized in quasi 1D Heisenberg ferromagnet.

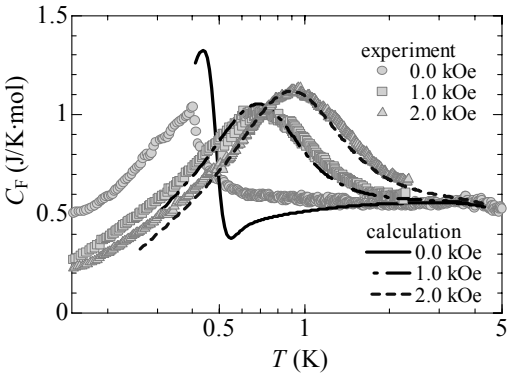

FIG.1: Specific heats of ferromagnetic chains in several magnetic fields. The contribution of lattice and antiferromagnetic chains are subtracted from the experimental data.

P-19 Pulsed-NMR Studies of Monolayer ^{3}He near the Mott Localization

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We measured spin-spin relaxation time (T_2) and magnetization of monolayer ^{3}He adsorbed on a graphite surface preplated with a monolayer ^{4}He by pulsed-NMR in a wide temperature range (100 μK ≤ T ≤ 500 mK). An intrinsic T_2 could be obtained without being affected by inhomogeneities of applied magnetic fields by use of the spin echo technique even at T = 100 μK. T_2 in the Mott localized phase, the 4/7 phase with competing exchange interactions of the order of 1-10 mK, decreases with decreasing temperature continuously down to the lowest temperatures likely due to the short-range spin ordering. Magnetization data that could be measured with better precision than previous cw-NMR measurements [1, 2] also show a continuous increase down to the lowest temperatures. These data support the gapless spin-liquid hypothesis for the 4/7 phase claimed previously [2, 3]. The density dependence of T_2 at T = 100 mK shows a V-shaped minimum at the density ($\rho_{4/7}$) for the 4/7 phase. At $\rho < \rho_{4/7}$, T_2 is determined by the motional narrowing presumably due to the zero-point vacancies. On the other hand, at $\rho > \rho_{4/7}$, T_2 seems to be governed by the interlayer exchange due to the layer promotion of ^{3}He.

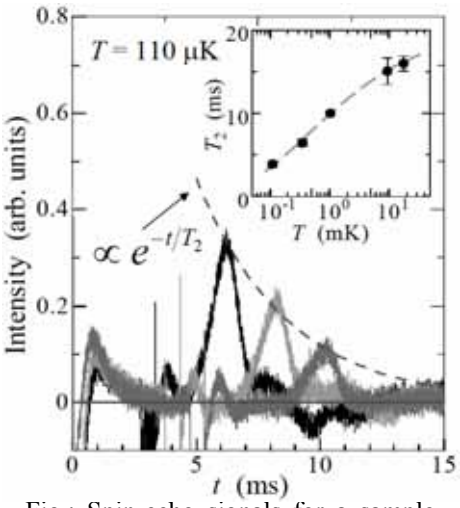

Fig.: Spin-echo signals for a sample of ρ = 6.46 nm^{-2} at T = 110 μK. The inset shows a temperature dependence of T_2.

[1] S. Murakawa, Y. Matsumoto, H. Akisato, M. Mukai, D. Tsuji, H. Kambara and H. Fukuyama, *to be published*.

[2] R. Masutomi, Y. Karaki, and H. Ishimoto, Phys. Rev. Lett. **92**, 25301 (2004).

[3] K. Ishida, M. Morishita, K. Yawata and H. Fukuyama, Phys. Rev. Lett. **79**, 3451 (1997).

P-20 NMR studies of the metallic phase near the Mott transition in κ-$(ET)_2Cu[N(CN)_2]Cl$

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The quasi-two-dimensional organic conductor κ–$(ET)_2Cu[N(CN)_2]Cl$ (denoted by κ-Cl hereafter) is a prototypical Mott insulator with an effectively half-filled band and undergoes the bandwidth-controlled Mott transition under soft pressure (~ 30 MPa). As shown in Fig. 1, the Mott transition is a first-order transition with a finite-temperature critical endpoint [1, 2]. Around the critical point, the critical phenomena of Mott transition are emergent. In κ-Cl, the critical exponents of Mott transition are found to be unconventional [3]. This anomalous criticality is an intriguing issue [4].

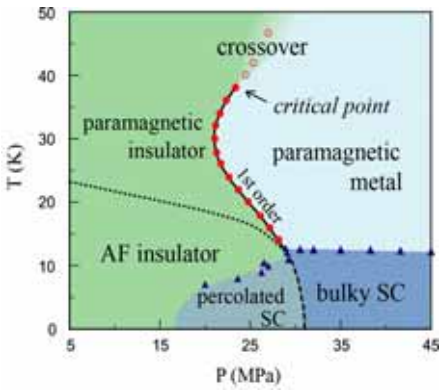

Fig. 1: Pressure-temperature phase diagram of κ–$(ET)_2Cu[N(CN)_2]Cl$ [2].

In this poster, we discuss the electronic states of metallic phase near the Mott transition in κ-Cl. The ^{13}C-NMR measurements were performed under helium gas pressure. The spin-lattice relaxation rate divided by temperature $1/T_1T$ and the Knight shift are found to be temperature-dependent even at low temperatures, although both quantities are expected to be constant in the case of conventional metals. This feature may be inherent in the metallic phase near the bandwidth-controlled Mott transition having a low-temperature endpoint.

[1] S. Lefebvre *et al*., PRL **85**, 5420 (2000) [2] F. Kagawa *et al*., PRB **69**, 064511 (2004); PRL **93**, 127001 (2004). [3] F. Kagawa *et al*., Nature **436**, 534 (2005). [4] M. Imada, PRB **72**, 075113 (2005).

P-21 Heat Capacity Measurements of Density Fluctuations in 2D ^{3}He

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We are studying novel low-temperature properties of monolayer ^{3}He adsorbed on a ^{4}He-preplated graphite surface (^{3}He/^{4}He/gr). This is a prototype system of strongly correlated two-dimensional (2D) fermions. Recently, we have found the emergence of a new quantum state containing a considerable amount of the zero-point vacancies (ZPV) up to 20% in a ^{3}He density (ρ) region of $0.8 \leq \rho/\rho_{4/7} \leq 1$ in this system [1]. Here $\rho_{4/7}$ (= 6.86 nm^{-2}) is the density of the Mott localized phase, the so-called "4/7 phase". The measured heat capacities (HC) show the anomalous coexistence of two round peaks at distinct temperatures, T_l^p (≈ 2 mK) and T_m^p (= 10-70 mK) in that density region. From the analyses based on the Hubbard model, we concluded that the two peaks are associated with the spin exchange interactions and the kinetic energy of the ZPV, respectively. This conclusion seems to be consistent with the previous workers' HC data ($T \leq 2$ K) for ^{3}He/^{3}He/gr system [2] which suggest the existence of third HC peak (T_h^p) due to density fluctuations (U^*) above 2 K.

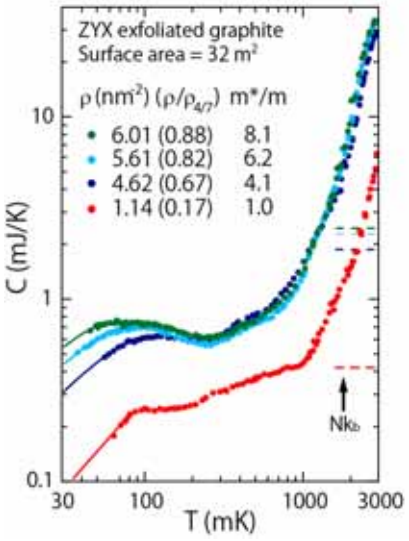

FIG.1: Heat capacities of 2D ^{3}He on ^{4}He-preplated graphite. The horizontal dashed lines are values of Nk_B, where N is the number of ^{3}He atoms. The solid lines represent the $C = \gamma T + \mathit{IT}^2$ behavior in the degenerated region.

In this work, we measured HC of ^{3}He/^{4}He/gr system in a wide temperature range (30 mK ≤ T ≤ 3 K) in order to determine the value of U^* directly and to study the nature of the order-disorder transition of the 4/7 phase. The data show thermally activated behavior (Schottky-type) with two activation energies of about 5 and 20 K (Fig.1). These may correspond to density fluctuations associated with the layer promotion from the second to third layer and that from the third layer to vacuum, respectively.

[1] Y. Matsumoto, D. Tsuji, S. Murakawa, C. Bäuerle, H. Kambara and H. Fukuyama, *to be published*.
[2] S. W. Van Sciver and O. E. Vilches, Phys. Rev. B **18**, 285 (1978)

P-22 Superfluidity of ^{4}He Confined in a Porous Glass and Pore Size Effects

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Nano-sized systems, whose sizes are intermediate between molecules and bulk materials, are intriguing objects due to their novel features, resulting from their sizes, shapes and surface conditions. ^{4}He confined in nanoporous media is one of the most interesting nano-sized systems in the context of an interacting Bose system, and has been investigated experimentally and theoretically. Recently, Yamamoto *et al.*[1] developed a strong suppression of superfluidity and a novel quantum phase of ^{4}He induced by extreme confinement into the nanoporous glass, suggesting an important role of the restricted geometry for the superfluid phase. The aim of the present work is to control the pore size of nanoporous media and clarify the correlation between the superfluidity of ^{4}He confined in the porous media and their pore size, where monolayer adsorption of noble gas, except for He, is taken place in order to control the pore size of nanoporous host materials.

A commercial porous Gelsil glass with pores of 5 nm nominal diameters is employed as a porous host. As the gas for the pore size control by monolayer adsorption, Kr is employed. The monolayer adsorption of Kr is performed at 77 K, where the vapor pressure of Kr is 220 Pa. The surface area and the pore diameter distribution of the porous glass before and after the Kr adsorption are estimated by N_2 adsorption and desorption isotherms at 77 K. The superfluid response of the ^{4}He confined in the porous sample is measured with a torsional oscillator method down to 10 mK. The pore diameter of the as-purchased Gelsil was estimated at 5.8 nm. Monolayer adsorption of Kr reduces the pore size to 4.7 nm, which can be described by the thickness of the Kr monolayer. The decrease in the pore size lowers the superfluid λ line of ^{4}He confined in the porous glass by 40 mK.

[1] K Yamamoto *et al*., Phys. Rev. Lett. **93** (2004) 075302.

P-23 ODLRO in a solid structure

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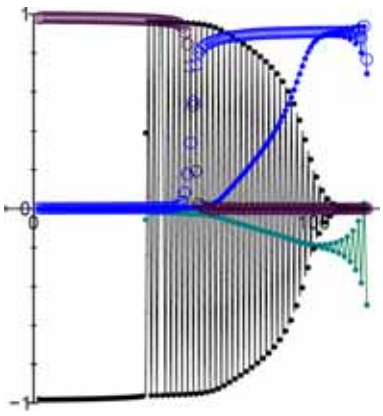
We will study the possible realization of the so-called super-solid state in tight-binding boson model. First we study the coexistence of the OLRO and ODRLO in the hard-core boson model, i.e., the Matsubara-matsuda model in a lattice with an inhomogeneous interaction. We found several regions with qualitatively different ordered states. In particular, we found the super fluidity coexists with two different types of stripe structures of the density. We also discuss relations among several definitions of super solid state. Furthermore, we study the effect of multi-occupation of particles on a site, i.e., the soft-core effect. We study effects of competition between the on-site interaction U and the nearest-neighbor repulsion interaction V, which can be interpreted by the effective flatness of the potential



P-24 Path integral calculation of a ^{4}He in a 0D-Nanopores model

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Recently many experimental approaches of ^{4}He particles confined in a porous geometry are carried out and many fascinating phenomena are observed. In this work, we confine a few ^{4}He particles in a modeled nano-scale sphere and compute internal energy, a particle density profile utilizing a path integral Monte Carlo calculation. The inner radius of the sphere is 8.0 Å. The introduced ^{4}He particles are solidified on the wall because of the strong adsorption potential and forms the first layer. This first layer plays a role of reducing the inner space of the sphere in our model. In order to simplify the model we deal with the first layer as a rigid body wall. Therefore we make a model of a sphere which has 5.0 Å effective inner radius and a rigid wall. In the calculation, we employ Aziz potential as the ^{4}He particle-particle interaction potential. We also deal with a distinguishable particle case in the system in order to understand the role of the boson statistics and particle exchange effect. In the temperature region T<2K, the energy difference between two statistics cases became large. In the case of boson, the energy depends on the particle number in the cage and showed boson like character in spite of a few body system.

P-25 Anomalous behaviors of edge magnetoplasmon resonance in helium surface state electrons

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b:Department of Physics, Graduate School of Sciences, Kyushu University, Ropponmatsu 4-2-1, Chuo-ku, Fukuoka 810-8560, Japan
c:Research Center for Low Temperature and Material Sciences, Kyoto University, Kitashirakawa-Oiwakecho, Sakyo-ku, Kyoto 606-8502, Japan

We are studying magnetotransport properties of two-dimensional (2D) surface state electrons (SSEs) on liquid helium. We employed an edge magnetoplasmon (EMP) resonance technique to measure the magnetic conductivities of SSEs in an applied magnetic field perpendicular to SSEs. The EMP is a collective oscillation mode in 2D electron systems in perpendicular magnetic fields where charge density fluctuations propagate along the edge of the system.

According to Volkov and Mikhailov theory [1], the resonance frequency and the linewidth of EMP are proportional to SSE density, in the classical regime where the Drude model is valid. In this report, all data were measured at temperature 0.21 K and magnetic field 3.2 T. By controlling the holding voltage, we measured SSE density dependence of the EMP resonance frequency and linewidth. When the SSE density is saturated, the measured resonance frequencies and linewidths agree with the results of the Drude model. However, at unsaturated SSE densities, we found that the behavirs of the EMP deviate from the Drude law. At constant holding voltage, the resonance frequency shows maximum and the linewidth shows minimum as a function of SSE density.

We show the data and discuss the origin of the deviation.

[1] V.A.Volkov, S.A. Mikhailov, in: V.M. Agranovich, A.A. Maradudin (Eds.), Modern Problems in Condensed Matter Sciences, Vol. 27.2, North-Holland, Amsterdam, 1991, p.855 (Chapter 15)

P-26 Superfluid Onset and Heat Capacity Anomaly of ^{4}He in One- and Three- Dimensional Nanopores

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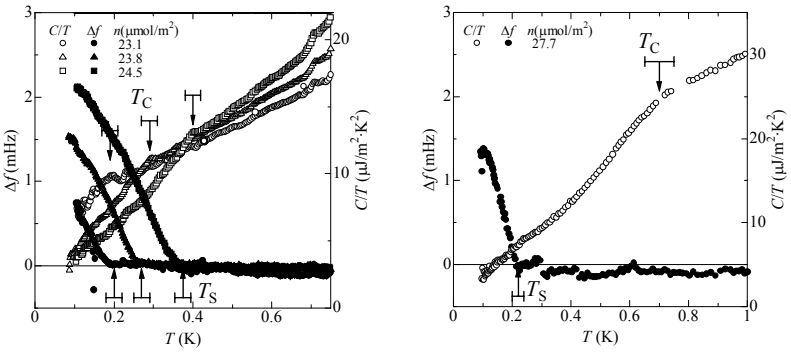
We have measured heat capacity and superfluid density of ^{4}He films formed on one-dimensional (1D) nanopores, FSM-16, and three-dimensional (3D) nanopores, HMM-2. The 1D nanopores are 2.8 nm in diameter and about 300 nm in length. The 3D nanopores are 2.7 nm in diameter connected with a period 5.5 nm. In the 3D nanopores, we observed a peak of the heat capacity(T_C) at an onset temperature of the superfluidity(T_S) shown in the left figure, which is a typical character of the 3D superfluid transition. On the other hand, heat capacity of ^{4}He adsorbed on the 1D nanopores shows rather broad anomaly at T_C shown in the right figure, and a superfluid onset at T_S, far below T_C. This obvious difference is likely to come from the dimensionality of the pore connection.



Heat capacity and superfluid response of torsional oscillator of ^{4}He in 3D(left figure) and 1D(right figure) nanopores

P-27 ^{3}He Boltzmann Gas Formed on Three-Dimensional Nanopores of HMM-2

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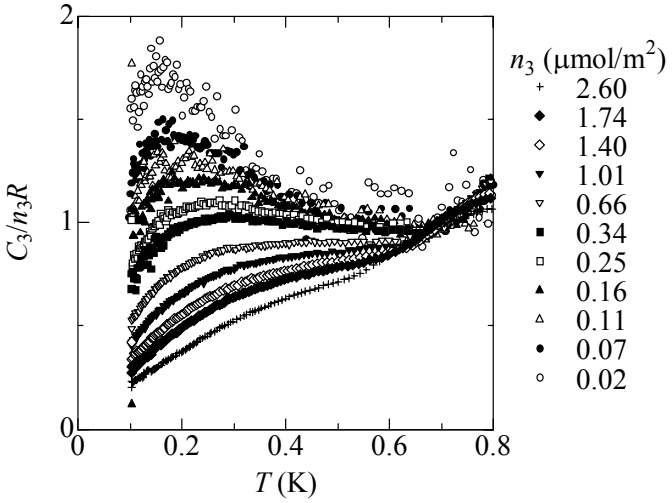
We have measured the heat capacity of ^{3}He adsorbed on three-dimensional nanopores whose diameter is 2.7 nm, and which is connected with a distance 5.5 nm, preplated with about 1.4 layers of ^{4}He. At low coverages of ^{3}He, the ^{3}He heat capacity is roughly constant at the measured temperatures between 0.1 and 1 K. Its molar heat capacity is on the order of the gas constant R, between 1.1 R and 1.8 R. This suggests a Boltzmann gas state of the adsorbed ^{3}He. At high coverages, the heat capacity is likely approaching linear in T at low temperatures, which suggests a degenerate state at further lower temperatures.



Heat capacity of ^{3}He adsorbed on HMM-2 preplated with 21.7mmol/m^2 (1.4layers) of ^{4}He

P-28 Frequency Dependence of Dynamic KT Transition in ^{4}He films

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At finite frequencies, a dynamic Kosterlitz-Thouless (KT) theory predicts a frequency dependence of the superfluid transition in ^{4}He films on planar surfaces. We report results of QCM measurements to study the superfluid response on planar gold surfaces for very high frequencies up to 180 MHz. In our previous experiment from 0.6 K to 1.0 K, as the frequency was increased, we observed the expected KT behavior that the superfluid transition shifts to a higher temperature from the static transition temperature T_{KT} and the transition temperature region is broadened. The frequency dependence of the dissipation peak temperature at the transition agrees with a simple equation of the frequency dependence induced from the dynamic KT theory given by Minnhagen. It gives a microscopic parameter for the dynamic transition, the ratio of the diffusion constant to the square of the vortex core radius D/r_0^2. We are currently extending these measurements down to lower temperatures.

P-29 Cooling rate dependence and annealing effects for supersolidity in solid ^{4}He

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Since the observation of "supersolid" state was reported by Kim and Chan (KC), a number of groups have attempted to confirm superfluidity of solid ^{4}He. We have performed torsional oscillator studies for solid ^{4}He formed in a cylindrical cell [1]. The observed frequency shift and dissipation confirm the observation of KC, but the origin of "supersolidity" has not been clarified.

In case the supersolidity is caused by defects in solid ^{4}He, the supersolidity is expected to depend on the quality of the crystal and to show strong annealing effects. We have examined the cooling rate dependence and the annealing effects for supersolidity.

The solid samples are prepared by cooling liquid ^{4}He under isochoric conditions. When the rate of cooling is high (0.1K/min), the frequency shift is twice larger than that of low cooling rate samples. The frequency shift and dissipation decreased after the sample was annealed for 1 day near the melting point. On the other hand, no annealing effect is observed in the low cooling rate samples. These behaviors strongly suggest that lattice defects formed in the crystal growth process play an important role on supersolidity of ^{4}He.

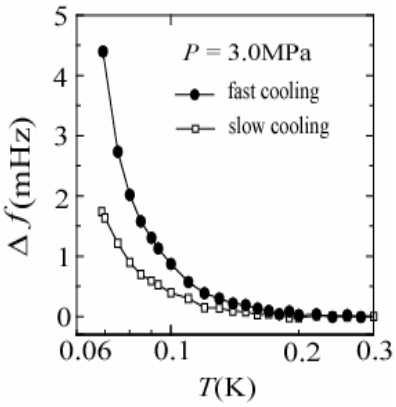

FIG.1: Frequency shift of the torsional oscillator at different cooling rate samples.

[1] M.Kondo *et al*., J.Low.Temp.Phys., to be published

P-30 Heat Capacity of ^{4}He Confined in Nanoporous Glass

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Confinement of ^{4}He in nanosized restricted geometory alters the properties of ^{4}He drastically. We have studied a phase diagram of ^{4}He confined in a nanoporous Gelsil glass which has 2.5 nm pores by a torsional oscillator method [1] and a constant pressure measurement [2]. The former studies revealed that ^{4}He in Gelsil undergoes a quantum phase transition from superfluid to nonsuperfluid phase at 0 K and P_c = 3.4 MPa (Figure 2). It is suggested that the nonsuperfluid phase is a localized Bose-Einstein condensation (LBEC) state, in which long-range order is destroyed by pore distribution or random potential.

In order to reveal the nature of the nonsuperfluid phase, we perform heat capacity measurements. Figure 1 shows typical data. As the sample cell contains bulk liquid ^{4}He, the heat capacity of ^{4}He in Gelsil C_{Gelsil} is obtained by subtracting the bulk ^{4}He heat capacity. It is found that C_{Gelsil} has a broad peak at about 1.95 K denoted by T_{peak}. Fig.2 shows the phase diagram of ^{4}He in Gelsil and T_{peak} obtained by the present measurements. T_{peak} are higher than the superfluid transition temperature T_c, suggesting that the broad peak in C_{Gelsil} is originated from the formation of LBEC. We will present the results of the pressure dependence of the peak temperature T_{peak}.

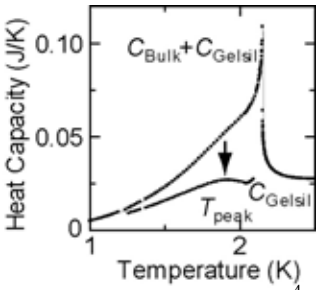

Fig. 1: Heat capacity of ^{4}He in Gelsil glass at 0.25 MPa.

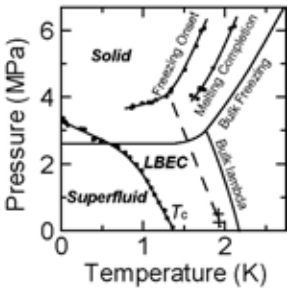

Fig. 2: *P*-*T* Phase Diagram. The cross(+) indicates T_{peak}.

[1] K. Yamamoto *et al*., Phys. Rev. Lett. **93** (2004) 075302.
[2] K. Yamamoto *et al*., AIP Proceedings **850** (2006) 349.

P-31 Development of a Low Temperature Scanning Probe microscope

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Scanning Probe Microscopy (SPM) has broad utility in studying surfaces on nanoscale, and has been applied to a great number of condensed matter studies. SPM working at very low temperatures will provide us with a powerful means for studying quantum phenomena on atomic scales. We develop a low temperature SPM which works down to 10mK. Our SPM is based on Frequency Modulation Atomic Force Microscopy (FM-AFM).

In FM-AFM, an oscillator circuit drives a high Q cantilever at its resonance frequency. The frequency shift that arises from tip-sample interaction is used as the probing signal. As Q tends to be high at low temperatures, FM detection is quite suitable for low temperatures, compared to other conventional AFM techniques. We employ a quartz tuning fork as a cantilever. It is also suitable for low temperature use, because of negligible heat production in operation and small temperature dependence in the resonance frequency.

As a preliminary experiment, we have succeeded to obtained images of a grating in vacuum at room temperature [FIG.1]. Low temperature experiments down to 1K are underway.

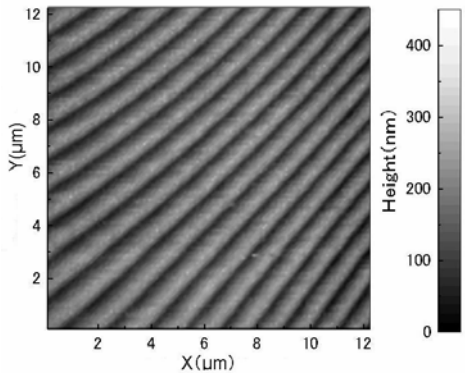

FIG.1: An image of a grating in repulsive force region.

P-32 Anomalous Sound Attenuation in "Superfluid ^{4}He-97% Open Aerogel" System

H. Tsuboya[1], K. Ohmori[1], K. Yoshino[1], S. Abe[1], H. Suzuki[1], H. Tsujii[1], K. Matsumoto[1], D. A. Tayurskii[2]

[1] *Graduate School of Natural Science and Technology, Kanazawa University, Kakuma-machi, Kanazawa, 920-1192, Japan*
[2] *Physics Department, Kazan State University, Kazan 420008, Russia*

We have studied the acoustic properties of liquid helium filled in various aerogels. The longitudinal ultrasound velocity and attenuation were measured at the frequency of 6 and 10 MHz with aerogels that had porosity from 92 to 97%. The soft aerogel skeleton leads to a modification of the pressure wave. The mode intermediate between first and fourth sound was observed. The dense aerogel with large sound velocity caused sound velocity to increase. The attenuation of this mode monotonically decreased with decreasing temperature for dense aerogels. However, an attenuation maximum was observed around 1.6 K for 97% open aerogel at various liquid pressures. This attenuation maximum increased with frequency. In the present work, we discuss the possibility of the sound modes conversion between first, second sound in superfluid and aerogel sound mode in this composite system.

P-33 Solidification and Melting of Hydrogen Confined in Nanoporous Media

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Hydrogen (H_2) is the lightest molecule in nature. The triple point of *para*-hydrogen is 13.8 K. If its solidification is suppressed below the triple point, strong quantum effects such as Bose-Einstein condensation (BEC) and superfluidity are expected in the supercooled liquid state at low temperatures.

Several works revealed that H_2 adsorbed or confined in porous Vycor glasses, which have nanopores of 6-8 nm in diameter, was supercooled down to 9-11 K. However, no signatures of quantum effects have been observed.

In order to realize the further suppression of the solidification and search for a quantum liquid state, we perform pressure measurements of H_2 confined in two pieces of Gelsil glass, which have nanopores of 2.5 nm and 5 nm. We study the effect of confinement for the melting/freezing curve in the pressure-temperature phase diagram, which may imply quantum effects as in the case of helium.

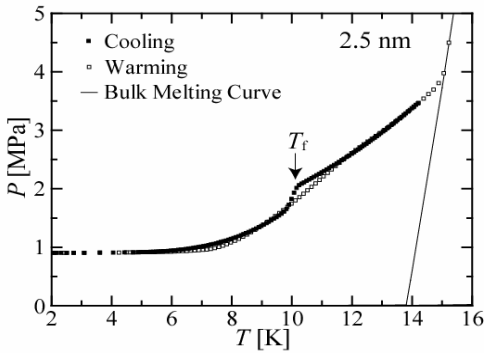

Fig.1. Pressure change of sample space with 2.5 nm Gelsil. The sharp drop in pressure at T_f indicates increase in density.

Figure 1 shows pressure change of sample space with 2.5 nm Gelsil. We have observed a sharp drop in pressure at T_f which indicates liquid-solid phase transition of hydrogen in pores. The freezing point is shifted form the melting/freezing curve of bulk hydrogen and is lower than the freezing point of hydrogen in Vycor. The pressure-temperature phase diagram obtained from this measurement will be discussed.

P-34

Low Temperature Heat Capacity of ^{4}He in One-Dimensional Nanopores

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We have studied heat capacity of ^{4}He adsorbed on one-dimensional (1D) pores of FSM-16 whose pore diameters are 1.8, 2.2, and 2.8 nm, respectively. Adsorbed ^{4}He shows a significant difference with ^{3}He in heat capacity at high coverages, where Bose statistical property of ^{4}He appears. In this region, low temperature heat capacity has a component proportional to temperature (see Fig.1), which is considered to be 1D phonon heat capacity. It might be explained as follows. Heat capacity relating ^{4}He motion in the cross-section of the pore is negligible at low temperature if gap energy of the motion is higher than ten times the thermal energy k_BT. Then motion along the pore causes the 1D phonon heat capacity. We would like to discuss about the ground state of ^{4}He in the region. Also, it is very interesting whether there is superfluidity at finite temperatures or not.

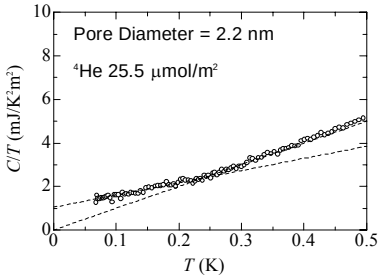

FIG.1: Heat capacity divided by temperature of ^{4}He adsorbed on 1D pores. A low-temperature part of C/T has a finite intercept.

P-35 **Superfluidity of Liquid ^{4}He Confined in 1D Nano-porous Media**

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We have studied the superfluidity of liquid ^{4}He confined in 1D nano-porous media. The porous medium used is one of the FSM16 series, which possesses straight pores 2.8 nm in diameter. The pellet was prepared by pressing FSM and silver powders in a 2:1 mass ratio. The volume ratio of inside the pore to outside FSM powder is 7:3.

Figure 1 shows the frequency shift as a function of temperature divided by the superfluid transition temperature outside FSM powder, T_{c_out}. For 0.1 MPa, the frequency deviates upward at 0.89 K. This deviation can be attributed to the superfluidity inside the pore. The deviation temperature decreases drastically with increasing pressure up to 1.7 MPa. Above that, the pressure dependence becomes weak and the deviation disappears abruptly above 2.3 MPa. Between 1.7 and 2.3 MPa, the temperature dependence of the deviation is different from that at lower pressure. The deviation increases gradually down to the lowest temperature, while its magnitude is suppressed with increasing pressure. The two-stage pressure dependence suggests that the phase of ^{4}He in the pore changes at 1.7 MPa.

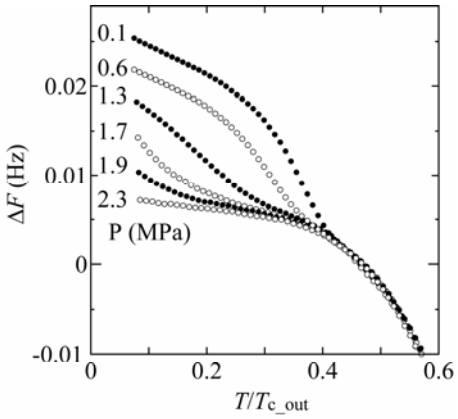

Fig. 1. Frequency shift (ΔF) as a function of the normalized temperature. The temperature is divided by the transition temperature outside FSM powder, T_{c_out}, and ΔF is the frequency shift from $0.47T_{c\_out}$. Numbers indicate the pressure.

P-36 High Sensitive QCM Coated with Mesoporous Silica Films

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The superfiuid density of ^{4}He confined or adsorbed in porous media have been extensively measured by various techniques, as the porous structures remarkably affect the properties of the superfluid transition. Recently many kinds of mesoporous silicate films have been produced [1], which suggests us a new possibility to measure the superfluid response in mesopores by the quartz crystal microbalance (QCM) technique driving at much higher frequencies (1～200MHz) than the conventional low-frequency oscillator of the torsion pendulum (～1kHz). In this presentation, we report our success in making a high-sensitive QCM coated with the mesoporous silicate film SBA-15 having around 5nm pores. From a nitrogen isotherm at 77K, the BET surface area is estimated to be 112 cm^2, and the mass sensitivity is enhanced by a factor of 120 from the original plane QCM with retaining a high Q factor, 8.5×10^4. This QCM technique is expected to be useful for various studies of the superfluid transition, such as the superfluid critical phenomena and the pressure effects of ^{4}He confined in the mesopores [2]. We are currently preparing the test at the lower temperatures down to 1K.

[1] Miyata *et al*., Nat. Mater. **3**, 651-656 (2004)
[2] Yamamoto et *al*., Phys. Rev. Lett. **93**, 075302 (2004)

P-37 Metastable State of Interfacial Friction of ^{4}He Films

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We measured the sliding friction of ^{4}He films adsorbed on Grafoil using the quartz crystal microbalance (QCM) technique. In the low temperature regime, this friction remains metastable after switching of the oscillation amplitude, before relaxing to the value determined by the amplitude. The relaxation of this friction is qualitatively different for decreasing and increasing amplitude. In the former case, the relaxation depends strongly on temperature and has a quasi-exponential time-dependence, while it has a quasi-logarithmic one in the latter case. We can explain both cases of relaxation by a model of a small low-friction domain which is created or annihilated by overcoming a potential barrier.

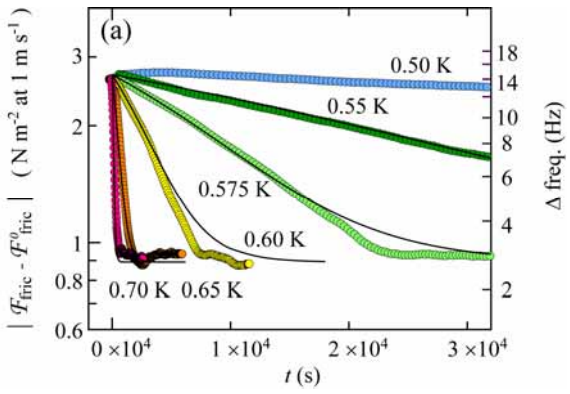

FIG.1: Relaxation after decreasing the oscillation amplitude from 1.0 nm to 0.2 nm for a ^{4}He areal density of 23 atoms/nm^2. The change in sliding friction is plotted on a logarithmic scale, and the corresponding value of the resonance frequency is shown on the right.

P-38 Heat Capacities of ^{4}He and ^{3}He Adsorbed on Cages of NH_4-Y Zeolite

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Y-type zeolite has void cages of 1.3 nm in diameter connected through apertures about 0.8 nm in diameter. In the previous study for Na-Y zeolite [1], quantum fluids of ^{3}He and ^{4}He were suggested at coverage 45-60% of the full pore. Considering the cage geometry, it was proposed that quantum cluster of a few atoms are formed in each cage [2]. In each cage of Na-Y zeolite, there may be a large heterogeneity of the adsorption potential caused by Na^+ cations on the pore walls. To exanimate quantum clusters in the cages with uniform potential profiles, we started heat capacity experiments using NH_4-Y zeolite which has a small cation potential. This experiment is currently undergoing, and the measured data are partly shown in Fig.1. In the poster we will show results of ^{4}He and ^{3}He adsorbed on NH_4-Y zeolite.

[1] H. Kato et al., J. Phys. Soc. Jpn. **55** (1986) 246

[2] S. Tasaki, Prog. Theor. Phys. **93** (1995) 857

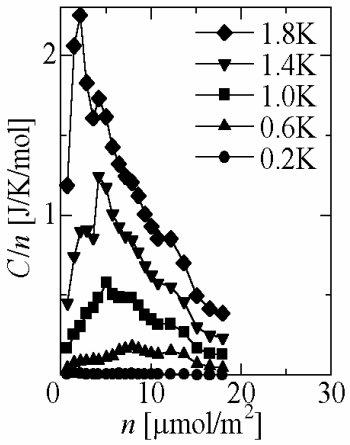

Fig.1: Heat capacity isotherms of ^{4}He adsorbed on NH_4-Y zeolite

P-39 Comparison of the Superfluidity in Nano-porous Glass between an Ultrasound and a Torsional Oscillator

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In order to study the superfluidity in nano-porous glass, we have developed the simultaneous measurement of an ultrasound and a torsional oscillator, and have measured ^{4}He films and liquid ^{4}He in the low pressure region. For ^{4}He films, the superfluid onset is clearly observed by means of both measurements. The transition temperature *T*c is in almost agreement with each other. However, the fraction of the decoupling mass shows a different behavior. For the torsional oscillator, the fraction increases rapidly below *T*c, and becomes almost constant as the temperature is lowered. In contrast, for the ultrasound, it increases linearly at low temperatures although a rapid increase is observed near *T*c. In addition, the fraction for the ultrasound at 0.1K is 1.6 times larger than that for the tortional oscillator. For liquid ^{4}He, similar behavior is observed.

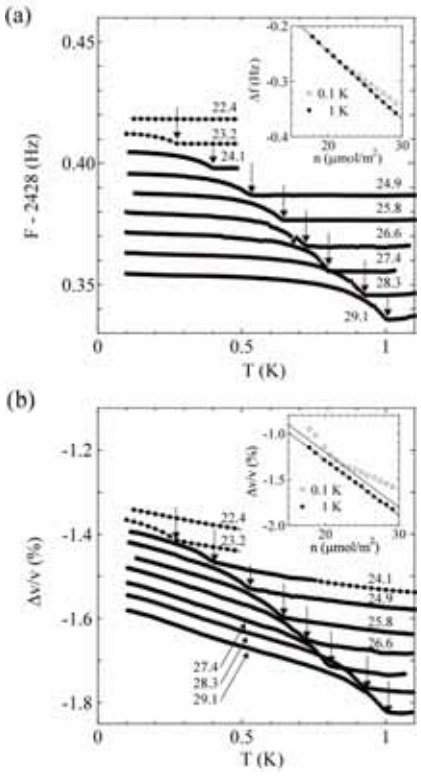

FIG.1: (a) Resonance frequency of the torsional oscillator with ^{4}He films at several densities. Inset: Decrease of the resonance frequency at 1 K and 0.1 K from the empty sample. (b) Sound velocity of the Gelsil sample with ^{4}He films at several densities. Inset: Decrease of the sound velocity at 1 K and 0.1 K from the empty sample. The numbers are areal densities of ^{4}He films (μmol/nm^2).

P-40

Sliding Friction of Kr films on Graphite

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The sliding friction of ^{4}He films on Grafoil depends strongly on the layer structure. It is interesting whether other adsorbates show a similar behavior. Thus motivated, we started the quartz crystal microbalance (QCM) measurement for Kr films on Grafoil. Figure 1 shows the resonance frequency as a function of Kr areal density. For the submonolayer region, the frequency does not decrease, which means that the friction is significantly small. In contrast, at the second layer condensation, the frequency drops drastically and the friction becomes large. As the areal density increases further, the frequency becomes almost constant. This suggests that the second layer slides relative to the underneath.

At present, in order to study the sliding direction dependence of Kr films on graphite, we are preparing single-crystalline graphite as the substrate.

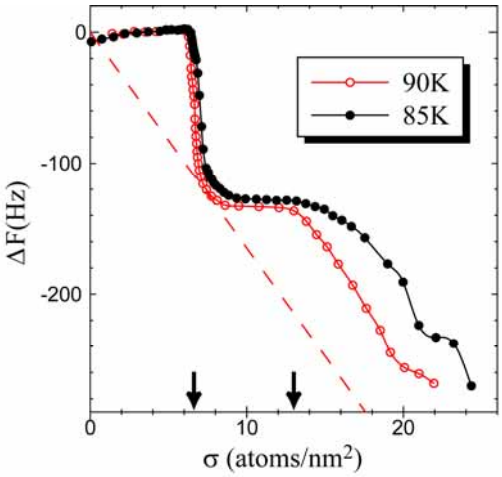

FIG.1: Decrease in the resonance frequency at 80 K and 95 K as a function of Kr areal density. The dashed line corresponds to the mass loading when Kr films are locked to the oscillating substrate. The arrows represent the second and third layer condensations.

P-41

Vortex-Core Structure in Fermion Superfluid with Population Imbalance

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The quantized vortex is a hallmark of superfluidity in a rotating quantum system. In the case of Fermionic superfluid, it is known that the discreteness of quasiparticle bound states in the vortex core causes the quantum depletion of atomic densities, which has been observed by the recent experiment [1] as direct evidence for superfluidity. However, the presence of the imbalanced spin densities in two-component Fermions drastically changes the core structure, such as the strong localization of the excess atoms in the vortex core.

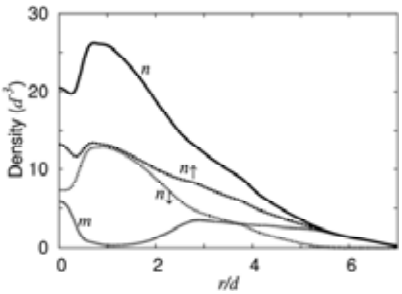

FIG: Each spin density $n_\sigma(r)$ and the polarization $m(r)$ at $P = (N_\uparrow - N_\downarrow) / (N_\uparrow + N_\downarrow) = 0.3$.

On the other hand, the population imbalance also allows the system to take the Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) states, which has modulation of the pairing in the vicinity of the surface. In order to understand the relationship between these two different topological objects: the vortex and the FFLO due to population imbalance, we theoretically investigate the vortex core structure in Fermionic superfluids with population imbalance based on the microscopic theory. We fully take into account both the effects – the quantized vortex and FFLO modulation of the pairing.

It is concluded that the resulting density profile keeps the visibility of the vortex core up to vicinity of the critical population imbalance [2].

[1] M. W. Zwierlein, J. R. Abo-Shaeer, A. Schirotzek, C. H. Schunck, and W. Ketterle, Nature, **435** (2005) 1047.
[2] M. Takahashi, T. Mizushima, M. Ichioka, and K. Machida, Phys. Rev. Lett. (in press; cond-mat/0607147).

P-42 Superfluidity of dilute ^{3}He fluid adsorbed on 4/7 phase

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The second layer of ^{3}He adsorbed on ^{4}He film (adsorbed on the flat surface of graphite) solidifies when its density is nearly 4/7 of that of the first layer. We study the possibility of superfluidity of the ^{3}He fluid added on 4/7 phase system. We assume that it is comfortable for added ^{3}He to be in pocket among ^{3}He forming 4/7 phase in the second layer. We consider honeycomb lattice tight-binding model for ^{3}He's hopping. Namely, the Hamiltonian for the added ^{3}He is expressed as

$$\mathcal{H} = \sum_{<i,j>} \sum_{\sigma} t c^{\dagger}_{i\sigma} c_{j\sigma} + \sum_{i} U n_{i\uparrow} n_{i\downarrow} + \sum_{i,j} \sum_{\sigma,\sigma'} V_{ij} n_{i\sigma'} n_{j\sigma} ,$$

where we assume the nearest-neighbor hopping, the second term the on-site repulsion, and the third term the Lennard-Jones interaction between nearest or next nearest-neighbor sites.

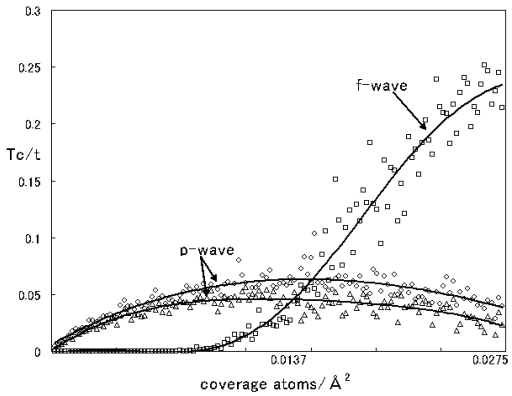

FIG.1: Transition temperature of superfluid of ^{3}He added to 4/7 phase system. Tc of p-wave and f-wave cross each other.

We find that it is possible for p-wave and f-wave superfluid(BW-like) state to appear in some range of ^{3}He coverage.

P-43 Vortex pinning to a solid sphere in helium II

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In recent years, there has been increasing interest in visualizing quantum turbulence. PIV (Particle Image Velocimetry) has been recently implemented in liquid helium by several experimental groups. PIV is based on injecting many micron-scale tracer particles into the liquid; one can observe the velocity configuration by monitoring particle's motion. In visualizing the velocity field, however, we must assume that vortices are not trapped by tracer particles. On the other hand, Lathrop's group has observed that the tracer particles in He II are aligned along the vortices by vortex pinning, which means visualization of quantized vortex [1]. The vortex pinning is a key issue in both experiments.

Schwarz numerically investigated vortex pinning on a hemispherical protrusion on a plane boundary [2]. In our model, we consider vortex pinning on a sphere at rest. As an initial state, we consider two plane boundaries, the sphere at rest at the middle of them and a straight vortex expanding between two planes, and follow the vortex dynamics. As a result, the vortex is captured by the sphere even at 0 K. And it is seen, by changing a distance between the sphere and the vortex of an initial state, there is a critical distance beyond which the vortex is no longer captured by the sphere. Moreover, looking at temperature dependence, we find the mutual friction is significant in making the vortex approach the sphere when the vortex is further than the critical distance. Those results provide the criterion how far the tracer particle located from the vortex can capture it in the experiments.

[1] G. P. Bewley *et al.*, Nature Vol. 441, 588 (2006)
[2] K. W. Schwarz, Phys. Rev. B **31**, 5782 (1985)

P-44 Development of Ultra-high resolution MRI and studies on the shape of phase-separated ^{3}He-^{4}He mixtures near the tri-critical point

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[2]*Graduate School of Science, Kyoto University, Kyoto 606-8502*
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Ultra low temperature and high magnetic field environment gives us high signal to noise ratio (SNR) of NMR. By exploiting this high SNR, we have been developing an ultra-high resolution MRI, MRI Microscope. Our ultimate goal is to achieve (1 μm × 1 μm) 2 dimensional spatial resolution. In order to attain the goal, we also need to suppress spin diffusion effects. Therefore, we are also developing large magnetic field gradients and new pulse sequences. Testing the limitation of the spatial resolution, we performed ULT-MRI [1][2] to visualize the interface of phase-separated ^{3}He-^{4}He mixtures at a higher magnetic field environment. We increased magnetic field from 0.33 T to 0.92 T, and magnetic field gradient from 0.25 T/m to 0.5 T/m. We were able to improve the resolution from (25 μm × 25 μm) to (6 μm × 6 μm). At 0.7 K, we found the contact angle of the interface against a stycast sample cell wall to be a few degrees. However, we still have ambiguity in determination of the interface position, especially near the wall. In order to resolve this problem, we prepared a new sample cell to visualize the shape of the interface in a small tube (ID 200 μm) at higher field (7T). We will report on preliminary results from the new sample cell.

This MRI microscope will be applied for imaging the vortex lattice of rotating superfluid ^{3}He-A phase, where the core structure does not have cylindrical symmetry if it is the double core vortex and the triangular lattice is deformed due to the uni-axial symmetry of the A phase.

[1] Y. Sasaki et al., J. Low Temp. Phys. **113**, 921 (1998)
[2] T. Ueno et al., Physica **B284-288**, 2057 (2000)

P-45 Boundary Magnetism and Superfluidity of Liquid ^{3}He in Nanometer-sized Porous Alumina

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

Continuous-wave NMR measurements were performed for liquid ^{3}He in porous alumina [1] with nominal pore size of 20 nm in diameter, at temperatures down to 0.3 mK. The signal is composed of two contributions: from the liquid and from the boundary solid layer of ^{3}He on the alumina's surface. The latter shows a well-known ferromagnetic tendency and signal intensities can be fitted to a Curie-Weiss law in the high temperature region. The obtained Weiss temperatures are 0.2 and 0.5 mK in 7.5 and 28 bar, respectively. The ^{4}He coverage (4 monolayers) completely eliminate boundary signal between 7.5 bar and 32.5 bar. The residual liquid signal shows frequency shift and broadening below superfluid transition temperatures dependent on liquid pressures. The obtained P-T phase diagram well resembles that of bulk liquid ^{3}He in spite of the very narrow pore-size comparable to the coherenth length of superfluid ^{3}He. It is now under investigation what texture should be achieved in such nanometer-sized pores.

[1] Anopore membrane, product of Whatman Inc.

P-46 Two-fluid Model of Rotating Ferromagnetic Superfluid ^{3}He-A1 by using the Spin Second Sound

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The A1 phase of the triplet superfluid ^{3}He is very unique and characterized by being composed of one spin species of the up-up pair and a uni-axial symmetry in space. Spin supercurrent is carried together with the mass supercurrent. The A1 phase exists in a very narrow temperature range at high magnetic fields, where $T_{c1} - T_{c2} = 52\ H$ (μK/T) and .T_{c1} and T_{c2} are the transition temperatures of A1- and A2-phases, respectively and H is an applied field. There has not been much research carried out in the A1 phase. In A1 phase, the spin second (entropy) sound has been studied and it was found that the attenuation of the sound due to intrinsic dissipation mechanisms is rather small near T_{c2}.[1].

In superfluid ^{3}He, quantum fluid dynamics has been extensively studied and has explored interesting features, which are caused by order-parameter with multi-components. Among them, many types of quantized vortices have been found in the superfluid A and B phases, where non-singular and soft core vortex and double-core vortex with circulation n > 1 have been investigated under rotating superfluid ^{3}He. Most of the work on vortices have been studied by using NMR, where NMR spectrum gave important information about the structure of the vortex core or the textural change due to flow. However, in A1-phase, we need to apply strong magnetic fields where the dipole torque on spin is negligible, compared with the Zeeman torque, and thus we can not extract much information on the vortices from NMR.

Here we propose to study the vortices and flow by using the spin second sound in A1 phase. The dissipation due to vortex occurred through the mutual friction force of spin supercurrent with normal fluid and the extra-damping due to vortices at the low frequency limit is given as $\Delta\alpha \sim B\Omega / 2c_2$, where Ω is a rotation speed and c_2 are the velocity of the spin second sound and B is the mutual friction coefficient. The coefficient B is sensitive to the core structure of the vortex. We do not have any information about what vortices exist in the A1 phase and the coefficient., B. We report a feasibility study on the two-fluid model of the rotating A1 phase by using the spin second sound in superfluid A1 phase under rotation. We compare the attenuation of the second sound due to vortices with those of the intrinsic ones and discuss the limit of sensitivity of the coefficient B at 8 Tesla.and a rotation speed of 1 rotation/ sec.

[1] T. Sato, J. J. Colemam, P. G. N. de Vegver, H. Kojima, and Y. Okuda, Phys. Rev. Lett. **84**,1515 (2000)

P-47 Coherent Magnetization Precession of superfluid ^{3}He in aerogel

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M. Kubota[1], O. Ishikawa[3], and Yu. M. Bunkov[15],

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[2]*Department of Physics, Graduate School of Science, Kyoto University, Kyoto 606-8502, Japan*
[3]*Graduate School of Science, Osaka City University, Osaka 558-8585, Japan*
[4]*Research Center for Low Temperature and Materials Sciences, Kyoto University, Kyoto 606-8502,*
[5]*Centre de Recherches sur les Tres Basses Temperatures, CNRS, 38042, Grenoble, France*

In superfluid ^{3}He-B phase, a spatially coherent precession of magnetization can be realized with magnetic field gradient, which is named Homogeneous Precessing Domain (HPD). The stability of HPD is governed by the spin stiffness of the order parameter and by the spin-orbital coupling, and the spin supercurrent supports the spin precession with a single frequency. We observed HPD of superfluid ^{3}He-B phase in aerogel and we found that HPD had a relatively large dissipation due to the pinning of topological defects and that rotation break HPD due to the introduction of additional topological defects. On the other hand, in bulk superfluid ^{3}He-A phase, the similar state is unstable because the dipole energy has a convex shape against the tipping angle because the orbital part of the order parameter *l*-vector and the spin part *d*-vector are parallel each other in the bulk. When *l*-vector is perpendicular to *d*-vector, the dipole energy has concave shape on the tipping angle and the coherent precession was predicted to be stable. In our aerogel sample, *l*-vector is almost perpendicular to *d*-vector due to the axial deformation and a coherent precession of magnetization was observed in A-like phase near the A-B transition temperature.

[1] Yu. M. Bunkov and G. E. Volovik, Europhys. Lett., **21**, 837 (1993)

P-48 Turn Around Experiments of Superfluid ^{3}He in Aerogel

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Aerogel provides a unique system to investigate superfluidity of liquid ^{3}He, because the average distance between the silica strands is comparable to the superfluid coherence length, and the diameter of each strand is minute. Therefore, aerogel acts as an impurity which does not destroy the superfluidity completely but does suppress the transition temperature and the superfluid density. Moreover, it has been discovered recently that the A-like and the B-like phases coexist within a wider temperature range ($T_{A-} < T < T_{B+}$).

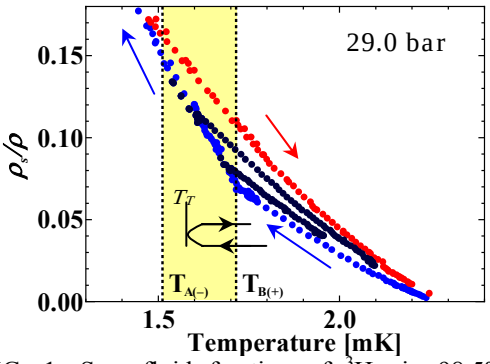

FIG. 1: Superfluid fraction of ^{3}He in 98.5% aerogel measured by the 4th sound technique. Blue and red traces represent the initial warming and cooling process respectively. Black traces represent the turn around process, showing the maintenance of the superfluid fraction at T_T.

We have used the fourth sound resonancen technique and performed so called "*Turn Around* Experiments" to study the coexsitent state; we cool the system from normal liquid to the certain temperature T_T and then warm up. When we choose this temperature to be $T_T < T_{A-}$ or $T_C > T_T > T_{B+}$, traces completely reproduce the initial one. But when we choose it to be $T_{A-} < T_T < T_{B+}$, as illustrated with the black arrow in FIG.1, traces come in between initial curves, and the A-phase fraction maintains its value at T_T. This behaviour has never been seen in ordinary liquid. This is the evidenece of the strong phase boundary pinning by aerogel strands, whose mechanism is not yet understood.

P-49 A-B Phase Transition of Superfluid ^{3}He in Cylindrical Aerogel

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[1] *Graduate School of Science, Osaka City University, Osaka 558-8585*
[2] *National Metrology Institute of Japan, National Institute of Advanced Industrial Science and Technology, Tsukuba 305-8563*

We have studied the A-B phase transition of superfluid ^{3}He in the 97.5 % porosity cylindrical aerogel by cw NMR method. We observed the coexistence of the A-like phase with the B-like phase and the phase conversion within the finite range of temperature. Figure 1 shows the temperature dependence of fractions of the A-like phase. On cooling from the normal state (●), the phase transition from the A-like to B-like phase occurs in the central part of the aerogel at first. And the A-like and the B-like phases exist in the central and the edge part, respectively. In the turn-around experiment (□) in which liquid ^{3}He is cooled from 1.473 mK after warming from nearby 1 mK, no phase conversion occurs in between gray regions in fig. 1. Below 1.360 mK, the spectrum of the A-like phase in the turn-around experiment is similar to that of the same fraction on cooling from the normal phase. This suggests that the phase transition from the B-like phase to A-like occurs in the edge part at first.

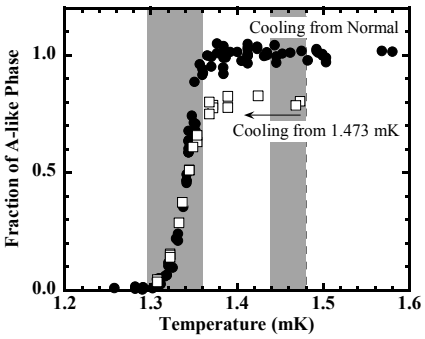

FIG.1: Temperature dependence of the fractions of the A-like phase in cooling from the normal state (●) and the turn-around experiment (□). The A-B phase transition occurs in gray regions, and not in between them.

P-50 Energy Loss of Fourth Sound in Superfluid ^{3}He

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The fourth sound resonance technique is one of the important methods to investigate the hydrodynamic property of the superfluid ^{3}He. We have measured the energy loss of the fourth sound in both superfluid ^{3}He with and without aerogel. The energy loss of the fourth sound, which is the inverse of the quality factor, is derived from the resonance line shape as a function of temperature.

FIG.1 shows the temperature dependence of the energy loss in with- and without-aerogel system at zero magnetic field and 29.0 bar. The energy loss in without-aerogel system monotonically decreases with decreasing temperatures, while the energy loss in with-aerogel system has the hysteresis due to the A-B phase transition; on cooling in the A-like phase it increases down to $T_{B(+)}$, then on further cooling, it starts to decrease in the A-B coexistent state, and in the B-like phase it is almost constant up to 2.0mK.

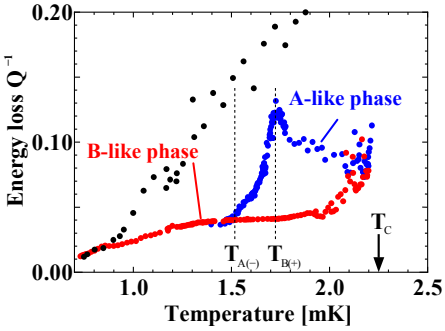

FIG.1: Temperature dependence of fourth-sound energy loss at 29.0 bar. Without aerogel (black) and with 98.5% porosity aerogel (blue ; cooling, red ; warming).

We found that the energy loss in without-aerogel system can be understood qualitatively and quantitatively by a hydrodynamic theory in the B phase[1], but that in with-aerogel system cannot. This shows that the viscous damping due to thermally excited quasiparticles in aerogel does not affect the energy loss of the fourth sound. The origin of the energy loss in with-aerogel system is not clear up to now.

[1] H.H. Jensen *et al., J. Low Temp. Phys.,* **51,** 81 (1983).

P-51 Studies of Strong Coupling Correction in Superfluid ^{3}He in Aerogel

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In the bulk ^{3}He strong coupling correction stabilizes the ABM state. In aerogel the remarkable reduction of this strong coupling correction is implied by some experimental fact that the AB transition curve has a positive slope $dT_{AB}(P)/dP>0$ [1] and the A_1-A_2 splitting has small aymmetry [2]. We examined impurity effects on the strong coupling contribution to quartic term of the Ginzburg-Landau functional. The strong coupling correction can be expressed by the quasiparticle 4-point vertex function. We calculated this vertex function with two methods. One is a perturbative analysis [3] both in the repulsive interaction and the impurity scattering and the other is phenomenological approach in which the vertex function is determined by experimental data like transport coefficients [4]. As a result impurity scattering weakens the relative stability of the ABM state to the BW state in both approaches, which doesn't contradict experimental fact.

[1] J.E. Baumgardner and D.D. Osheroff, PRL **93**, 155301 (2004).
[2] H.C. Choi, A.J. Gray, C.L. Vincente and et al., PRL **93** 145302 (2004)
[3] P. Brussaard, M.A. Baranov, M.Yu. Kagan and et al. Physica A **234** 643 (1997)
[4] J.A. Sauls and J.W. Serene, PRB **24** 183 (1981)

P-52
Spectroscopic Study of the Surface Density of States of Superfluid ^{3}He by Transverse Acoustic Impedance Measurements

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It is very fundamental problem to study surface density of states (SDOS) in superfluid ^{3}He. In unconventional superconductors and superfluids, scattering of quasi-particles modifies the local density of states significantly from the bulk one leading to the formation of Andreev bound states near a wall within the range of several coherence lengths. Since superfluid ^{3}He is the p-wave superfluid realized in the extremely pure system, its order-parameter and various bulk properties are well understood in contrast to the unconventional superconductors. So it provides a good opportunity to study the Andreev bound states in p-wave BCS states approaching from the well-known bulk superfluids. The characteristic subgap structure of SDOS in superfluid ^{3}He was calculated theoretically [1]. We measured the real and imaginary components of the transverse acoustic impedance Z of superfluid ^{3}He. The characteristics of the observed temperature dependence at various frequencies at a fixed pressure of 17.0 bar in Ref. 2 are reproduced by the results in B phase; a kink of the real component and a peak of the imaginary appeared at a particular temperature which decreased with increasing frequency. These features were observed in the low temperature region where the frequency was lower than the pair breaking energy 2Δ. The kink and the peak are the weak singularity which appears when the frequency is equal to Δ* + Δ. Δ* is the upper edge of the surface bound state band. The measured temperature dependence of Δ* was about 30% smaller than theoretical values (see Fig. 2) [3].

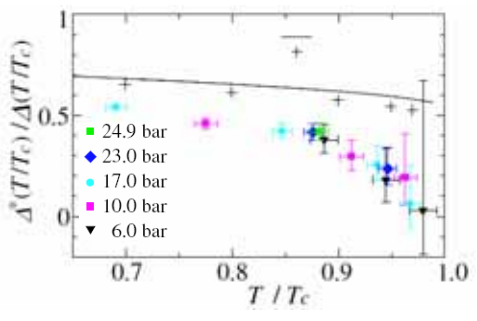

Fig.1: Temperature dependence of Δ* scaled to the bulk gap Δ.

[1] Y. Nagato *et al*., J. Low Temp. Phys. **110** (1998) 1135.
[2] Y. Aoki *et al*., Phys. Rev. Lett. **95** (2005) 75301.
[3] M. Saito *et al*., Phys. Rev. B rapid communication, in press.

P-53 NMR study of superfuid ^{3}He in anisotropic aerogel

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[2]*Department of Physics, Graduate School of Science, Kyoto University, Kyoto 606-8502, Japan*
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Pure superfluid ^{3}He is certainly among the most complex systems in condensed matter which are successfully described by a comprehensive theory. The influence of disorder on ordered states is one of the most interesting and ubiquitous problems in condensed matter physics. In the case of superfluid ^{3}He the disorder can be produced by its impregnation in high porosity silica aerogel. We will report the cw-NMR study on ^{3}He-A and ^{3}He-B phase order parameter orientation owing to the aerogel anisotropy (the aerogel prosity is 98%). In ^{3}He-A we have observed relatively homogeneous NMR line with an anomalously large negative frequency shift. We can attribute this effect to an orientation of orbital momentum along the axis of density anisotropy. The similar orientation effect we have seen in ^{3}He-B. We can measure the A-phase Leggett frequency, which shows the same energy gap suppression as in the B-phase

P-54 Self-Organization of Vortex Line Length Distribution in Dilute Quantum Turbulence

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There has been an exponential growth of interest in scale-free structure of quantum turbulence in recent years. Recent studies revealed that the vortex length distribution (VLD), meaning the size distribution of the vortices, in decaying quantum turbulence at zero temperature obeys a power law[1]. This power law is very important because it means that there is a kind of self-similarity in quantum turbulence during the decay. Unfortunately, however, there has been no practical study that answers the important question; why can the quantum turbulence acquire power law VLD? In our poster, we first propose that the nature of quantized vortices allows us to describe the decay of quantum turbulence with a simple model without loosing physical validity. This simple model well reproduces the observed power law and suggests that the emergence of power law VLD is a consequence of two mechanisms; Richardson cascade process and dynamical scaling law of vortex dynamics[2].

[1] T. Araki *et al.* Phys. Rev. Lett. **89** , 145301 (2002)
[2] A. Mitani and M. Tsubota, Phys. Rev. B **74** , 024526 (2006)

P-55 **Thermal Dissipation Mechanism in Gross-Pitaevskii Turbulence**

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The microscopic mechanism of thermal dissipation in quantum turbulence for dilute Bose gas is numerically studied by solving the coupled system involving the Gross-Pitaevskii equation and the Bogoliubov-de Gennes equation. At low temperatures, the obtained dissipation does not work at scales greater than the core size of quantized vortices, which supports the classical Kolmogorov law for quantum turbulence. However, as the temperature increases, dissipation works at large scales, dissipates vortices, and affects the vortex dynamics (FIG. 1).

We successfully obtain the mutual friction coefficients of the vortex in dilute Bose-Einstein condensates dynamics as functions of temperature. This study can be regarded as the first study elucidating the mutual friction of quantized vortices in dilute BECs

[1] M. Kobayashi and M. Tsubota., Phys. Rev. Lett. **97** (2006) 145301.

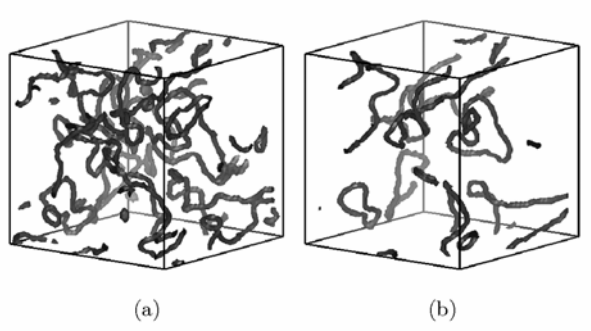

FIG. 1: Configurations of quantized vortices after some time development at $T = 0.01\ T_c$ (a) and $T = 0.1\ T_c$, starting from the same initial state. We can observe fewer vortices in (b) than in (a), which obviously conforms to the larger effect of dissipation to vortices.

P-56
Dynamical Properties of Non-equilibrium Superfluid-Normal Interface

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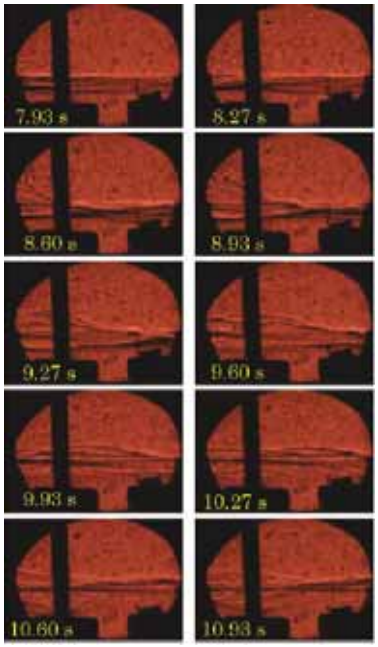
Non-equilibrium superfluid-normal (SN) interface was created by cooling liquid ^{4}He locally from the bottom. Typical value of a heat flow was 5 mW/cm^2 to maintain the interface in this experiment. The interface profile was visualized by a shadowgraphy or a schlieren method. We found that interfacial wave propagates at the SN interface as shown in figure[1]. The wave was generated by a heat pulse. Velocity and damping of the wave were about 1 cm/s and 0.5 1/cm, respectively.

We also investigated the interface profile near vertical walls of different materials to see "wetting" of the SN interface[2]. The interface touched a vertical glass wall at almost 90°. A large hollow was observed near a brass wall. Downward flow was observed on a copper wall due to the very good thermal conductivity of the wall. Various types of the interface profiles were observed depending on the thermal conductivity of the walls used.

[1] J. Taniguchi, R. Nishida, A. Ogino, R. Nomura and Y. Okuda, J. Jpn. Soc. Microgravity Appl. **23**, (2006) 134
[2] Nishida, J. Taniguchi, R. Nomura and Y. Okuda, to be published in J. Low Temp. Phys. (2007)



P-57

Generation and Detection of Quantum Turbulence by a Vibrating Wire in Superfluid ^{4}He

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We have studied the turbulence transition of the superfluid ^{4}He flow by a vibrating wire. At low drive force, the velocity of the wire increases linearly with drive force; consequently the flow around the wire indicates laminar flow. As drive force increases, the wire velocity suddenly drops at a certain drive force, where the flow develops into turbulence. It is clear that the transition is attributed to the vortex strings attached to the wire which expand unstably in the high velocity field.

We have found recently that the flow switches frequently between the laminar and turbulent flow regimes. Though the microscopic mechanism of the switching has not been explained yet, the switching must be related to generation and annihilation of vortex rings. Kobayashi *et al.* recently found the vortex rings in turbulence dissipates as excitations in their simulations. Ref.[1]

In this paper, we discuss the generation of turbulence and the detection of excitations in superfluid ^{4}He at very low temperature by using vibrating wires.

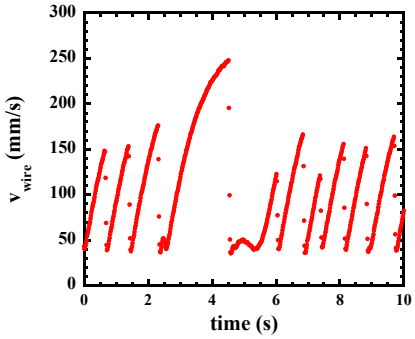

Fig. The switching between laminar and turbulent flows. The velocity of the wire increases from a value expected in turbulence (50mm/s) with a relaxation time, then drops to the initial value.

Ref.[1] M. Kobayahi and M. Tsubota, Phys. Rev. Lett **97** 145301

P-58

NMR Measurement of a quantized Vortex of Rotating Superfluid ^{3}He-*A* in a Single Narrow Cylinder

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We study a quantized vortex by cw-NMR in a single narrow cylinder with 100 μm radius in the *A*-phase under rotation, by using the ISSP ULT rotating cryostat. We observed a NMR signal of a single vortex, which is a typical continuous unlocked vortex (CUV) in the A phase with 2 vortex quanta and the same as a vortex observed in narrow multi-cylinders [1]. In this size of cylinder, the texture of order parameter is not homogeneous differently from bulk liquid. For example, the Mermin-Ho, the Pan-Am and the Disgyration textures can exist in this cylinder size.

The angular speeds of the first vortex incursion Ω_i and the withdrawal Ω_w are measured in this single cylinder. These angular speeds Ω_i and Ω_w are similar to the vortex incursion speeds measured in the multi-cylinders and so are related to the critical angular speed Ω_c defined by $F-L\Omega_c=0$ where F is free energy of the system and L is its angular momentum.

We plan to study dynamics of single vortex in the textures, such as a reconnection of vortexes and a pining between a wall and the end-point of a quantized vortex.

[1] R. Ishiguro *et al.*, Phys. Rev. Lett. **93**, 125301 (2004).

P-59 Nucleation and Crystallization of ^{4}He Induced by Acoustic Waves

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We report visual observations of the nucleation of a ^{4}He crystal by acoustic waves [1]. When an acoustic wave pulse is applied to superfluid ^{4}He which is slightly over-pressurized above the melting pressure, a ^{4}He crystal is nucleated on a piezoelectric transducer. This phenomenon is interpreted that an acoustic radiation pressure pushes the surface of a remnant seed crystal on the wall and that the crystal grows to a macroscopic size. We also found that acoustic waves can locally grow up or melt a crystal. Recently, very fast growth of the (0001) surface of a hcp ^{4}He crystal was observed by applying an acoustic wave pulse to the interface from the crystal side as shown in FIG.1 [2]. The image was taken by a high-speed camera which operated at a rate of 1 msec/frame. The growth velocity cannot be explained by the spiral growth mechanism for the known value of the step mobility. We developed a new step multiplication model for the facet growth by application of high-power acoustic waves.

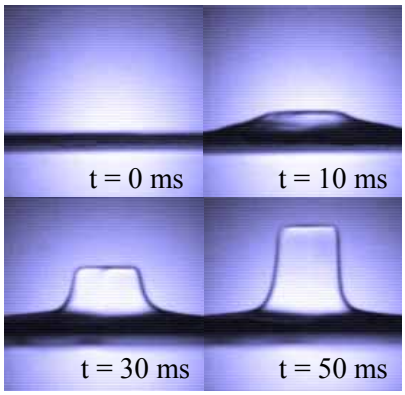

FIG.1: Growth shape of the c-facet taken by a high-speed camera at T = 200 mK. Pulse duration was 50 msec. Diameter of the c-facet was 3 mm at t = 50 msec.

[1] H. Abe *et al*., Phys. Rev. B, **71**, 124506 (2005).
[2] H. Abe *et al*., J. Phys. Soc. Jpn., **75**, 023601 (2006).

P-60 Faraday Instability of Crystallization Wave

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When a liquid is oscillated at a frequency 2ω in the vertical direction, the oscillation of the liquid surface occurs at the half frequency ω above a threshold oscillation amplitude. This is called Faraday instability and is regarded as a model system for the physics of pattern formation and nonlinear dynamics[1]. Since a crystal superfluid interface of ^{4}He behaves like a liquid surface due to very rapid crystal growth and the crystallization waves propagate at the interface at low temperatures, parametric excitation of the crystallization waves via Faraday instability can be expected[2]. Anisotropy of the crystal superfluid interface will lead to novel instability patterns. We report the first observation of the Faraday instability for crystal-superfluid interface as shown in FIG.1.

[1] M. Faraday, Philos. Trans. R. Soc. London **52**, 319 (1831).
[2] W. van Saarloos and J. D. Weeks, Phys. Rev. Lett. **74**, 290 (1995)

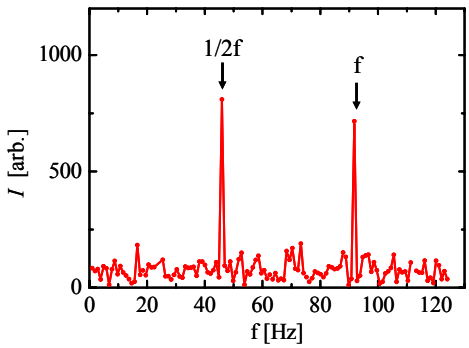

FIG.1: Fourier spectra of the brightness at a particular point of the high-speed camera image. Sample cell was oscillated at frequency f = 92.0 Hz at T = 150 mK. Crystallization waves were generated on the interface at one half of the oscillation frequency if the amplitude of the oscillation was large enough.

P-61 **Frequency dependence of Transition Velocity of Quantum Turbulence in Oscillatory Flow of Superfluid ^{4}He**

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We have studied the quantum turbulence in oscillatory flows of superfluid ^{4}He using vibrating wires at frequencies from 58 Hz to 6.7 kHz. At low driving force, the oscillatory flow around a vibrating wire is laminar. As driving force increases, a turbulent transition causes at a critical velocity (v_c). This transition is related to instability of remanent vortices. In recent years, various methods employing vibrating structures have been developed [1,2]; however, there is little data concerning the effect of the frequency of the flow. To investigate the mechanism of the turbulent transition, we used the vibrating wire method. Figure 1 shows the frequency dependence of the critical velocity at 1.3 K. Comparing our data with those form the micro sphere and the grid, the surface roughness and the size of structures are found to be insignificant, and the frequency of the flow plays important role in the quantum turbulent transition.

[1] J. Jager, B. Schderer, and W. Schoepe, Phys. Rev. Lett. **74** (1995) 566.

[2] H.A. Nichol, L. Skrbek, P.C. Hendry, and P.V.E. McClintock, Phys. Rev. E **70** (2004) 056307.

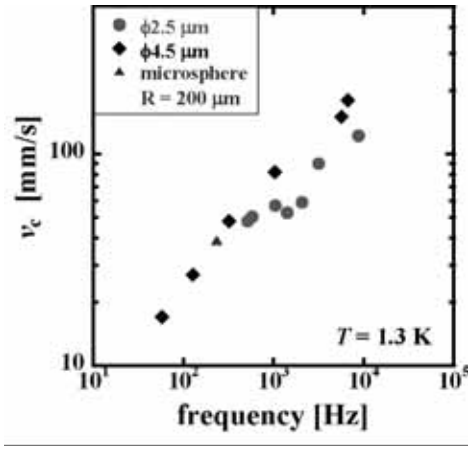

FIG.1: Frequency dependence of the critical velocity.

P-62 **Dynamical Vortex States of Bose-Einstein condensates in a rotating optical lattice**

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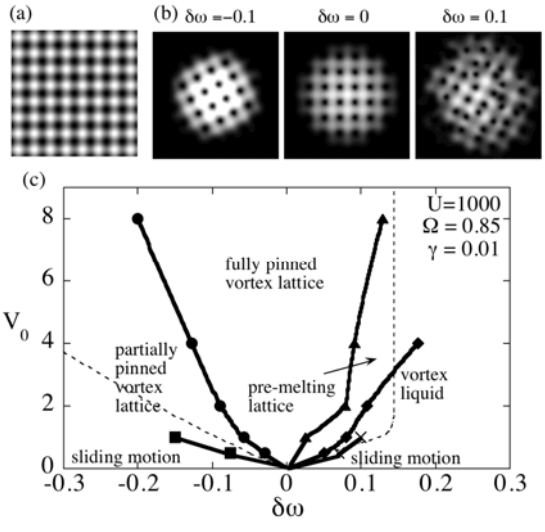
We present simulation results of the vortex dynamics in a trapped Bose-Einstein condensate in the presence of a rotating optical lattice [1]. Changing the potential amplitude V_0 and the relative rotation frequency $\delta\omega$ between the condensate and the optical lattice, we find a rich variety of dynamical phases of vortices, as shown in the right Figure. The onset of these different phases is described by the force balance of a driving force, a pinning force and vortex-vortex interactions. In particular, when the optical lattice rotates faster than the condensate, an incommensurate effect leads to a vortex liquid phase supported by the competition between the driving force and the dissipation.

[1] K. Kasamatsu and M. Tsubota, cond-mat/0608656 (2006)



P-63 Bosons in Disordered Optical Potentials

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Ultracold dilute Bose gases in optical trapping potentials are superclean systems known for their flexibility and controllability. Moreover, when the potential is an optical lattice, the system is an experimental realization of the well-known Bose-Hubbard model [1]. Optical lattices are defect-free but it is possible to add *highly controllable* disorder to the clean lattice. The type, the length scale and the strength of the disorder can all be manipulated. In addition the interatomic interactions in the dilute gas can be controlled experimentally. Hence, ultracold dilute Bose gases in disordered optical lattices offer many compelling advantages in studying the effect of disorder and interactions on the superfluid and condensate properties of bosons. This has resulted in increasing experimental (e.g. [2]) and theoretical interest (e.g. [3]).

In this work we find exact numerical solutions to the disordered Bose-Hubbard model for a range of different interactions, disorder strengths and types of disorder. We show that the existence of a normal condensate fraction can be identified with the Bose glass phase in the phase diagrams for different types of disorder and we discuss how the phase diagrams change for different types of disorder. We also calculate the spatial correlations in the Bose glass phase.

[1] D. Jaksch *et al.*, Phys. Rev. Lett. **81**, 3108 (1998).
[2] D. Clément *et al.*, Phys. Rev. Lett. **95**, 170409 (2005); C. Fort *et al.*, *ibid.*, 170410; T. Schulte *et al.*, *ibid.*, 170411.
[3] B. Damski *et al.*, Phys. Rev. Lett. **91**, 080403 (2003); R. Roth and K. Burnett, Phys. Rev. A **68**, 023604 (2003); N. Bar-Gill *et al.*, cond-mat/0603513 (2006).

P-64
BCS-BEC crossover in a gas of Fermi atoms loaded on an optical lattice

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[2]*Faculty of Science and Technology, Keio University, Hiyoshi 3-4-1, Kohoku-ku, Yokohama, Kanagawa, 223-0061, Japan*

We investigate the superfluid phase transition and strong-coupling effects in a two-component Fermi gas loaded on an optical lattice. When the lattice potential is strong, the system is well described by the attractive Hubbard model. The strength of a pairing interaction U, the hopping matrix element t between nearest-neighbor sites, and the particle density n (per site) are experimentally tunable. Extending the strong-coupling theory developed by Haussmann [1] in the superconductivity literature to the three-dimensional attractive Hubbard model, we calculate the superfluid phase transition temperature T_c as a function of U [2]. This strong-coupling theory is shown to satisfy the symmetry property of the Hubbard model that results for the particle density n are the same as those for 2-n in contrast to the Gaussian fluctuation theory [3].

In the half-filling case, we show that T_c takes a maximum value $T_c \sim 0.042\varepsilon_F$ in the intermediate coupling regime $U/zt \sim 0.9$ (where ε_F is the Fermi energy, and $z=6$ is the coordination number). We also point out that, although the Gaussian fluctuation theory is known to be a good approximation in the whole BCS-BEC crossover region in the absence of the lattice, it remarkably overestimates T_c in the intermediate coupling regime of the lattice system, where fluctuation effects are crucial.

[1] R. Haussman, Phys. Rev. B **49** (1994) 12975.
[2] H. Tamaki, Y. Ohashi, and K. Miyake, in preparation; Meeting Abstracts of the Physical Society of Japan **61** Issue 2, (2006) 84.
[3] P. Nozières, and S. Schmitt-Rink, J. Low Temp. Phys. **59** (1985) 195.

P-65 Zel'dovich-Starobinsky Effect in Atomic Bose-Einstein Condensates: Analogy to Kerr Black Hole

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We theoretically study the friction against the object rotating in atomic Bose Einstein Condensates (BECs) trapped in axisymmetrical potentials at T=0. The situation is connected to the Zel'dovich-Starobinsky (ZS) effect which causes the amplification and spontaneous emission of electromagnetic modes by the body or black hole rotating in quantum vacuum [1, 2]. The condition of the ZS effect is $\omega - q\Omega < 0$, where ω is the frequency of the mode, q its azimuthal quantum number along the rotation axis, and Ω the angular velocity of the rotating body. The rotating body in quantum vacuum loses energy and angular momentum through the ZS effect, slowing down the rotation. This is an example of the quantum friction.

The ZS effect can be simulated in superfluid, where the superfluid ground state plays the part of the quantum vacuum [3]. The quantum friction against the rotating body is due to spontaneous emission of phonons in superfluid of atomic BECs. We numerically investigate the critical angular velocity for breaking the frictionless rotational flow, which depends on the position of the rotating object. This study is done by the collaboration with G. E. Volovik and Ralf Schützhold.

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[2] A. A. Starobinsky, JETP **37**(1973) 28-32.

[3] A. Calogeracos and G. E. Volovik, JETP Lett. **69**(1999) 281-287, cond-mat/9901163 (1999).

P-66 Dynamics of vortex lattice formation in a rotating Bose-Einstein condensate with an optical lattice

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We study dynamics of vortex lattice formation in a rotating Bose-Einstein condensate with a blue-detuned square optical lattice (OL) by solving the two-dimensional Gross-Pitaevskii equation. By changing the depth and the periodicity of the OL, the dynamics shows the characteristic vortex nucleation and the lattice formation.

When the OL is shallow, the ripples occur along the surface of the condensate, generating the vortex cores. Then, the vortices go toward the rotational axis, forming the unpinned lattice (FIG.1). The lattice formation depends on the competition between the pinning due to the OL and the vortex-vortex interaction. In the deep case, owing to the strong pinning, the vortices form the pinned square lattice (FIG.1). When the periodicity is much larger than the healing length, especially, we have found the two kinds of the nucleation. One is same as the above nucleation from the surface. The other is the vortex pair creations excited by the peaks of the OL moving beyond the critical velocity in the condensate. The anti-vortices of the pairs disappear by coupling with other vortices. As a result, the remaining vortices form a square lattice. We hope that these results would be helpful to understand the experiment of the system [1].

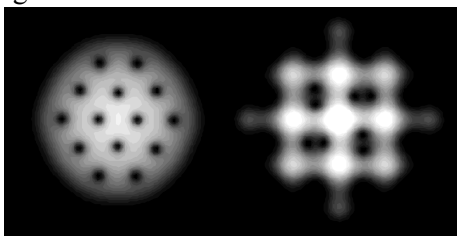

FIG.1: The left figure shows the vortex formation of the shallow case. The right figure shows that of the deep case. Both cases have the same periodicity.

[1] S. Tung *et al.*, condmat/0607697

P-67

Numerical Observation of Kolmogorov Spectrum in Rotating BEC II. Scaling and Anisotropic Properties in Energy Cascade

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The BEC in an atomic gas is created under a trap potential, which confines atoms inside a 3-D area, e.g., a cigar- shaped one. The rotation is usually given along an axis and the anisotropic rotation energy is injected into the BEC cloud. In this presentation, we discuss a notable anisotropic character specific to the trapped potential and clarify a size scaling issue of the spectrum. In Fig. 2, the energy spectrum in terms of k_z, i.e., $E(k_z)$, shows an anomalous power-law dependence which extends over a relatively wide range. This may characterize the anisotropic energy injection and cascade process in the rotating BEC. We will present more details in the presentation.

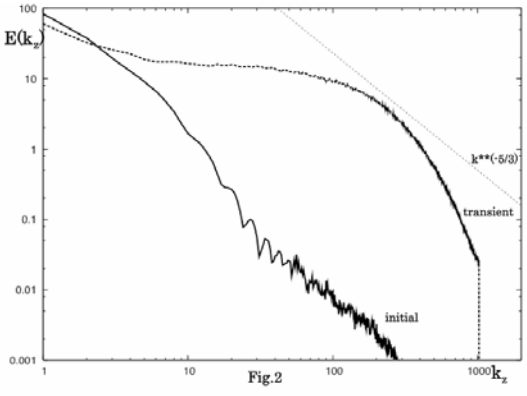

Fig.2

P-68

Ultracold Fermions with Repulsive Interactions Confined in One- and Two-dimensional Optical lattices

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Recent advances in laser techniques make it possible to realize the condensation of trapped atom gases. A remarkable example is a trapped fermionic system, where the BEC-BCS crossover is observed by tuning the strength of interactions. Furthermore, the coexisting state with metallic and Mott insulating regions is theoretically suggested for repulsive cases [1]. Since quantum fluctuations in the Mott insulating region are strongly affected by the dimensionality, the lattice structure, etc., the systematic analysis is indispensable for clarifying the ground state properties of the confined systems.

To address this problem, we investigate the 1D and 2D Hubbard models with harmonic confinement by means of the variational Monte Carlo simulations with *stochastic reconfiguration with Hessian acceleration* scheme [2]. By incorporating the site-dependent on-site correlations and the nearest neighbor doublon-holon correlations, we elucidate the ground state properties of the 1D confined system, which are consistent with those of the quantum Monte Carlo studies [1]. We further extend our work to the 2D system, and examine the density profile and the spin structure factor to discuss how the lattice structure affects the coexisting state with strong correlations.

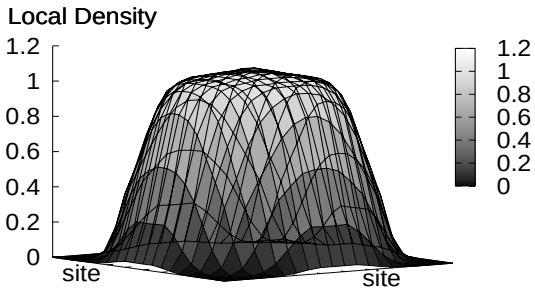

FIG.1: Density profile of the fermions confined in the 2D harmonic potential.

[1] M. Rigol et al., Phys. Rev. Lett. **91** (2003) 130403.
[2] S. Sorella, Phys. Rev. B **71** (2005) 241103

P-69 Spontaneous topological-defect formation in a spinor BEC

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Spontaneous formation of topological spin texture in a spinor Bose-Einstein condensate (BEC) has been predicted in Ref. [1] and observed in the Berkeley experiment reported in Ref. [2]. In this experiment, dynamics of quantum phase transition from the nonmagnetic phase to the magnetic phase was observed by a nondestructive in situ measurement.

Motivated by this experiment, we study the magnetization dynamics of the spinor BEC [3]. We show that the topological texture is formed in two steps: the spontaneous formation of domain walls followed by the creation of polar-core spin vortices (Fig. 1). We also show that the spin textures depend sensitively on the initial noise distribution, and find an appropriate noise to reproduce the experimental results. We point out that there is an analogy between the defect formation in a spinor BEC and that in a scalar BEC.

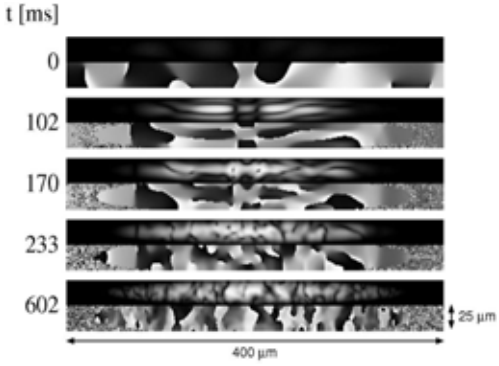

FIG.1: Magnetization dynamics of a ^{87}Rb BEC. The upper and lower panels show the magnitude and direction of the magnetization, respectively.

[1] H. Saito, Y. Kawaguchi, and M. Ueda, Phys. Rev. Lett. 96, 065302 (2006).
[2] L. E. Sadler et al., Nature 443, 312 (2006).
[3] H. Saito, Y. Kawaguchi, and M. Ueda, cond-mat/0610862.

P-70
Dynamical Properties of Fermions in a One-Dimensional Optical Lattice

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Recent substantial progress in laser cooling techniques has realized the quantum-degenerate atomic gasses at extremely low temperatures. This opens up a new research field making it possible to experimentally simulate the many-body problems via atomic gasses. Ultracold fermions confined in optical lattices are especially attractive in relation to condensed matter physics. It has been theoretically predicted that, in the ground state of such fermions, there appears the coexistence phase consisting of both the metallic and the Mott-insulating regimes under a certain condition [1]. One can expect this interesting feature to be observed experimentally in the near future.

In this report, we study the dynamical properties of interacting ultracold fermions trapped in a one-dimensional optical lattice. We apply the adaptive time-dependent density matrix renormalization group method [2] to the Hubbard model with a harmonic confinement. We explore how the correlated fermions evolve after the confining potential suddenly vanishes. The time evolution of the density profile and the momentum distribution is calculated for the two typical cases: the one where the initial ground state is supposed to be in the metallic phase and the other to be in the coexistence phase. We find that, in both cases, these quantities exhibit the unusual behaviors in their time dependence, which originates from the fermionic properties of atoms.

We thank T. Yamashita for valuable discussions at the early stage of the work.

[1] M. Rigol et al., Phys. Rev. Lett. **91**, 130403 (2003).
[2] U. Schollwöck, J. Phys. Soc. Jpn. **74**, (Suppl.), 246 (2005).

P-71 Imbalanced Superfluid State in the BCS-BEC Crossover

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Recent realization of paired superfluidity in trapped fermionic atoms interacting via a Feshbach resonance have opened a door for the quantitative study of the high-temperature superfluidity [1]. Much attention has been focused on equal mixtures of neutral fermions distributed in two hyperfine spin states, exhibiting the spin-singlet sueperfluid, a BCS-Bose Einstein condensate (BEC) crossover.

Recently two experimental groups have succeeded in producing *imbalanced* superfluid in two-component fermionic atoms [2], which provides a textbook material to explore an unsolved problem on the pairing mechanism of imbalanced two species. Here we try to address such a problem by numerical calculations based on the single-channel model with the Bogoliubov-de Gennes approximation. It is found that the low-temperature area of the resulting phase diagram in the BCS side of a resonance is dominated by the spatially oscillating, Fulde-Ferrell-Larkin-Ovchinnikov, pairing [3]. In contrast, there appears the superfluid-normal phase separated state with definite sign of the order parameter in the strong coupling BEC side.

[1] See for review, Q. Chen *et al*. Phys. Rep. **412**, 1 (2005).
[2] M.W. Zwierlein *et al*., Science **311**, 492 (2006); G.B. Partridge *et al*., Science **311**, 503 (2006).
[3] K. Machida, T. Mizushima, and M. Ichioka, Phys. Rev. Lett. **97**, 120407 (2006).

P-72 Vortex Lattice Structure of a Bose-Einstein Condensate in a Rotating Lattice Potential

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We study vortex lattice structures of a trapped Bose-Einstein condensate in rotating square and triangular lattice potentials by solving the two-dimensional time-dependant Gross-Pitaevskii equation. With increasing lattice pinning strength, we observe structural phase transition from triangular Abrikosov vortex lattice to pinned vortex lattice. We study the effect of the lattice potential in the vortex lattice structure by changing parameters such as angular velocity, pinning strength and lattice constant.

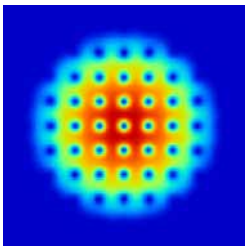

Fig.1 : Vortex lattice pinned by a square optical lattice potential.

P-73 **Dynamical properties of *F*=2 spinor Bose-Einstein Condensates**

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We have experimentally investigated and analyzed the dynamics properties of $F = 2$ ^{87}Rb Bose-Einstein condensates (BEC) in an optical trap. The $F = 2$ BEC is thought to have a new magnetic response in comparison with $F = 1$ BEC and many interesting spinor dynamics owing to its rich variety of internal degrees of freedom. Starting with condensate occupying $m_F = 0$, we observed different magnetic components, which is spin relaxations to $m_F = \pm 1$ and $m_F = \pm 2$, and the population oscillation between these states at certain magnetic field strength because of spin-mixing [1]. When the condensated atoms were initially in $m_F = \pm 2$ with same occupation at weak magnetic field strength, we found no spin relaxations of the two components in the trap shown in Fig. 1. These results are clear evidence of polar behavior and strongly suggest that the ground state of $F = 2$ ^{87}Rb BEC is antiferromagnetic [2].

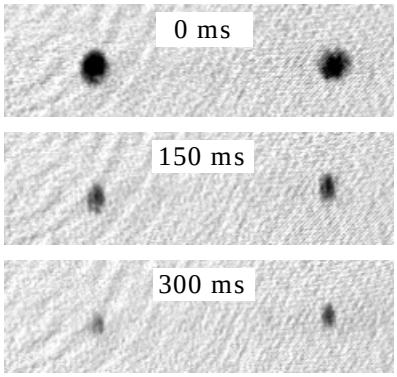

FIG.1: Time dependent observation of different m_F components separated by a Stern-Gerlach method.

[1] T. Kuwamoto *et al*., Phys. Rev. A **69**, 063604 (2004).
[2] H. Saito and M. Ueda, Phys. Rev. A **72**, 053628 (2005).

P-74 **Spontaneous Circulation in Ground-State Spinor Dipolar Bose-Einstein Condensates**

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We report on a study of ground-state phases in spin-1 ferromagnetic Bose-Einstein condensates (BECs) with magnetic dipole-dipole interactions. The long-range and anisotropic nature of the dipolar interaction can yield spin texture in a ground state. In particular, in ferromagnetic BECs, spin texture can be formed without increasing the short-range interaction energy. Therefore, even in a BEC with weak magnetic dipolar coupling, such as alkali atoms, spin texture spontaneously appears. Moreover, because of a spin-gauge symmetry of ferromagnetic BECs, mass flow can be generated by developing spin textures. In this work, we numerically explore the mean-field ground state and find three kinds of topological spin textures [1]. In particular, we identify chiral spin-vortex phase and show that this phase has substantial net orbital angular momentum, i.e., spontaneous circulation emerges. This phase also has chirality in the formation of the spin vortex. We predict that all phases can be observed in the spin-1 ^{87}Rb condensate by changing the trap frequency or the number of the trapped atoms.

[1] Y. Kawaguchi, H. Saito, and M. Ueda, Physical Review Letters **97**, 130404 (2006).

P-75 Dynamics of binary Bose-Einstein condensates in an optical trap

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We have studied the dynamics of binary ^{87}Rb Bose-Einstein condensates (BEC) in an optical trap. In our experiment, we first prepare $|F=2, m_F=-2\rangle$ BEC and then transferred their atomic state to $|F=1, m_F=-1\rangle$ by applying a microwave field of 6.8GHz. The power of the microwave field was adjusted so that the populations of $F=2$ and $F=2$ were equal. We observed that the binary BEC, initially overlapped spatially, separated with each other in several hundred milli seconds. This indicated that $|F=2, m_F=-2\rangle$ and $|F=1, m_F=-1\rangle$ BEC are immiscible. The spatial configuration is determined by the residual weak magnetic field gradient (~0.3mG/100μm) because $|F=2, m_F=-2\rangle$ is a strong field seeking state and $|F=1, m_F=-1\rangle$ is weak field seeking state. When the zero-field point is located left of the BEC, $F=2$ component moves right side s shown in Fig. 1(a). After $F=2$ component moved right side, we suddenly changed the zero-field point location from left to right of the BEC. The evolution after 200 msec and 400 msec are shown in Fig. 1(b) and (c), respectively. We have found that, during the spatial position exchange, domain structure appeared not only in $F=2$ component but also in the sum of $F=2$ and $F=1$ density as seen in Fig. 1(b).

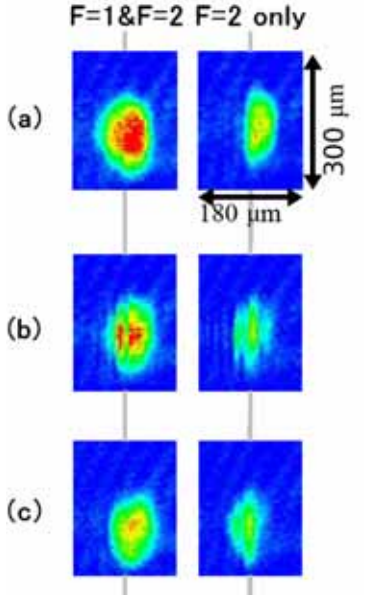

FIG.1:Time evolution of binary BEC.

P-76 Collective motion of the d-vector in Sr_2RuO_4

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It is very likely that spin-triplet superconductivity occurs in Sr2RuO4. There are many experimental results implying triplet pairing, but unquestionable evidence for it has not yet been obtained. Observation of collective excitations associated with triplet pairing must be definitive evidence. In particular, direct observation of collective motion of the d-vector would be the most direct one for spin-triplet pairing. In spin-symmetric systems, the d-wave collective mode is gapless (spin wave). Spin-orbit interaction makes it gapped, and if the frequency is much larger than the gap frequency, observation would be difficult. Many experiments on Sr2RuO4, however, appear to suggest that anisotropy in spin space caused by spin-orbit interaction is rather weak. This may make it possible to observe the spin wave excitation associated with d-wave collective modes directly in neutron experiments. I calculate the dynamical spin susceptibility in Sr2RuO4 taking account of d-wave collective motion, and find that a spin wave mode (resonance) appears in it. Observability of the mode is also discussed.

P-77 Polar Kerr Effect in Superconducting Sr_2RuO_4: Evidence for Broken Time Reversal Symmetry

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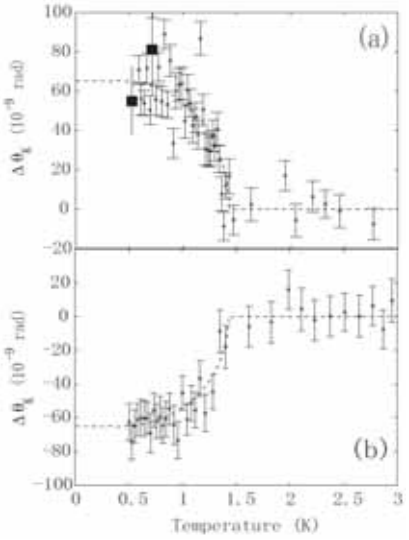
Polar Kerr effect in the spin-triplet superconductor Sr_2RuO_4 was measured with high precision using a Sagnac interferometer [1]. We observed non-zero Kerr rotations as big as 65 nanorad appearing below T_c. Our results imply broken time reversal symmetry in the superconducting state of Sr_2RuO_4, similar to ^{3}He-A.

The figures represent results of training the chirality with an applied field. They also indicate this effect is insensitive to the presence of vortices. a) + 93 Oe field cool, then zero field warm-up. The Kerr rotation $\Delta\theta_K$ is expressed in units of nanorad. b) – 47 Oe field cool, then zero field warm-up. Dashed curves are fits to a BCS gap.



[1] Jing Xia *et al*., Phys. Rev. Lett. **97**, 167002 (2006).

P-78 Improved wave functions for Hubbard model: Superconductivity and Mott transition

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The discovery of high-temperature superconductivity in cuprates has led to a considerable interest in understanding strongly correlated electron physics. It has been clarified that the Gutzwiller-projected wave function, whose parameters are numerically determined by variational Monte Carlo method, explains some experimental phenomena observed in cuprates. However, it is sometimes difficult to distinguish an artifact due to the restricted variational space from the true features, particularly superconductivity in the vicinity of Mott transition and effect of frustration by introducing next-nearest-neighbor transfer. It is desirable to extend the study of this class of wave functions to generate more accurate trial function. This will allow us to make a more systematic and comprehensive comparison between the theories and the experiments. Thus, we study an extended wave function for the two-dimensional Hubbard model with next-nearest-neighbor transfer, using the optimization variational Monte Carlo method. Two kinds of factors are newly introduced in our trial wave function:

(1) Configuration correlations between nearest-neighboring sites, including a doublon-holon binding.

(2) A renormalization effect of the quasi-Fermi surface owing to the electron correlation.

Using the extended many-body wave function for Mott transitions and *d*-wave superconductivity, it is found that (i) a doublon-multiholon (or holon-multidoublon) configuration becomes less advantageous, as the number of holons (doublons) sticking to a doublon (holon) increases in the large *U* region. (ii) The renormalized quasi-Fermi surface almost recovers the nesting condition in the large *U* region.

P-79 Symmetries of Superconductivity in a Model of Two Hubbard Chains Coupled with Ferromagnetic Exchange Interaction

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We study the ground-state properties of a model of two Hubbard chains coupled with ferromagnetic exchange interaction in order to seek for possible spin-triplet superconductivity. We first develop the weak-coupling theory for this model and find that the ground state has the spin gap and the system is in the state of spin-singlet d_{xy}-wave-like pairing. We then apply the exact-diagonalization technique and density-matrix renormalization group (DMRG) method for the strong-coupling region of this model, whereby we calculate the charge gap, spin gap, binding energy, pair correlation function, anomalous Green's function, and Tomonaga-Luttinger parameter for various interaction strength and band filling. We find that, in the region of intermediate to high electron densities, the ground state has the spin gap and the spin-singlet d_{xy}-wave-like pairing is dominant, in consistent with the results of the weak coupling theory, whereas in the region of low electron densities, we find that the fully spin-polarized state is stabilized and the system is in the state of spin-triplet pairing. The calculated results are summarized as the phase diagram in the space of the parameters and band filling. See Refs. [1,2,3] for details of our calculations.

[1] T. Shirakawa, S. Nishimoto, and Y. Ohta, in preparation.
[2] T. Shirakawa, Y. Ohta, and S. Nishimoto, Proceedings of ICM (Kyoto), in press.
[3] S. Nishimoto, T. Shirakawa, and Y. Ohta, Proceedings of M^2S-HTSC (Dresden), in press.

P-80 STM/STS Studies of Surface Electronic States of Sr_2RuO_4

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We studied a surface electronic density of states of a spin-triplet superconductor, Sr_2RuO_4, by low temperature STM/STS technique. It is known that detecting the superconducting quasi-particle spectrum on a cleaved surface along the *ab*-plane is not straightforward, possibly because of the surface reconstruction. We have done STM/STS measurements on surfaces cleaved at three different temperatures of 7 K, 100 K and 300 K in UHV. It turned out that the surface cleaved at temperatures below 100 K shows a large normal-metal gap (Δ~5 meV). On the other hand, the surface cleaved at 300 K shows a disordered electronic state in which DOS is roughly proportional to $|E\text{-}E_F|^{1/2}$. This energy dependence can be explained as the correction term of Anderson localization in three dimensions. These results indicate that the cleaved surface of Sr_2RuO_4 is rather unstable to show apparently different electronic states from that of bulk.

We thus are planning to take a new approach to this problem based on a recent prediction by Tanaka *et al*. [1]. Theory predicts that the midgap Andreev resonant state (MARS) can coexist with the proximity effect in diffusive normal-metal/triplet superconductor (DN/TS) junctions, while the MARS competes with the proximity effect in DN/singlet superconductor junctions. Therefore, detection of the enhanced proximity effect can be a crucial test to identify spin-triplet superconductivity. More specifically, the zero-bias density of states on the DN side is expected to *increase below* T_c of TS. We are starting to search for this enhancement of the proximity effect through thin gold layers on Sr_2RuO_4.

[1] Y. Tanaka, S. Kashiwaya, and T. Yokoyama, Phys. Rev. B **71** (2005) 094513.

P-81

Vortex States in Superconductors with Large Pauli-Paramagnetic Effect

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Quantitative estimate of the paramagnetic effect as well as the diamagnetic effect is important to understand the behavior of physical quantities in the mixed state of superconductors.

We study the vortex states under strong paramagnetic effect. By the selfconsistent calculation of pair potential and vector potential based on the quasiclassical theory, we demonstrate the significant contribution of the paramagnetic pair breaking and the induced paramagnetic moment around the vortex core, qualitatively estimating the H-dependence of low temperature specific heats $\gamma(H)$, Knight shift $\chi(H)$, magnetization and the flux line lattice (FLL) form factor. As presented in Fig.1, when paramagnetic effect is large (larger μ), $\gamma(H)$ and $\chi(H)$ show concave curvature at higher fields by the paramagnetic pair breaking. We realize strong paramagnetic contributions in $CeCoIn_5$ from the anomalous H-dependences of Knight shift of NMR and the FLL form factor of the small angle neutron scattering.

We also discuss the vortex states in the FFLO (Fulde-Ferrell -Larkin -Ovchinnikov) states.

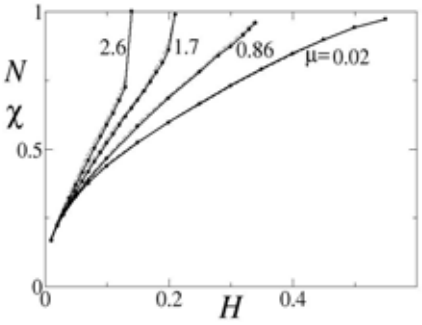

FIG.1: Magnetic field dependence of paramagnetic susceptibility $\chi(H)$ (solid lines) and low temperature specific heats $\gamma(H)$ (dashed lines) for various paramagnetic parameter μ. =0.02, 0.86, 1.7 and 2.6 at T =0.1T_c. $\chi(H)$ and $\gamma(H)$ normalized by the normal states values show the almost the same behavior.

P-82

Possible Structure of d-vector in Sr_2RuO_4 Based on Analyses of ^{17}O-NQR Relaxation Rates and Microscopic Model of Short-Range Ferromagnetic Spin Fluctuations

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Anomalous temperature dependence of ^{17}O-NQR relaxation rate in the superconducting state [1] strongly suggest that d-vector at zero magnetic field is along the ab-plane, i.e., perpendicular to the c-axis, in contrast to majority points of view that it is along the c-axis. We show that the spin-orbit interaction associated with relative motion of Cooper pairs causes a weak non-unitary state with the **d**-vector perpendicular to the c-axis and the internal Josephson oscillations gives rise to anomalous NQR-relaxation observed experimentally. Then, we review the result of Ref. [2] in which the local Coulomb repulsion U_{pp} at O site gives rise to short-range ferromagnetic correlations among molecular d-orbital with d_{xy} symmetry at adjacent Ru sites, inducing the Cooper pair with ($\sin k_x$+i $\sin k_y$) symmetry. Finally, we sketch how the state with d-vector perpendicular to the c-axis is stabilized by the spin-orbit interaction with atomic origin and the Hund–rule coupling among d_{xy}, d_{yz} and d_{zx}, orbitals, by the method discussed by Yanasa and Ogata [3] but on the basis of the model Hamiltonian used in Ref. [2].

[1] K. Mukuda *et al*., Phys. Rev. B **65** (2002) 132507.
[2] K. Hoshihara and K. Miyake, J. Phys. Soc. Jpn. **74** (2005) 2679.
[3] Y. Yanase and M. Ogata, J. Phys. Soc. Jpn. **72** (2005) 673.

P-83

Mixed-State Thermal Conductivity as a Probe of the Pairing Symmetry

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In a low temperature regime of a superconductor where the transport property is believed to be determined by the elastic impurity scattering, the thermal conductivity can provide important information on the pairing state. Recently, the thermal conductivity $\kappa(B)$ in a superconducting vortex state has attracted much attention to detect the pair potential symmetry [1].

The low temperature mixed-state thermal transport is mainly determined by the following three mechanisms; the impurity scattering which gives the Drude thermal conductivity in the normal state, the Andreev scattering by vortex cores, and the Doppler shift effect due to the supercurrent. So far, two approximations have been frequently used to calculate the mixed-state thermal conductivity. One is the so-called Doppler shift approximation [2]. This method neglects the Andreev scattering by vortex cores, and thus is valid only near the lower critical field H_{c1}. The other one is the so-called Brandt-Pesch-Tewordt approximation [3]. Since the latter approximation neglects the spatial variation of the normal Green's function, it is valid only near H_{c2}. At present, there is no theoretical work valid from H_{c1} to H_{c2}.

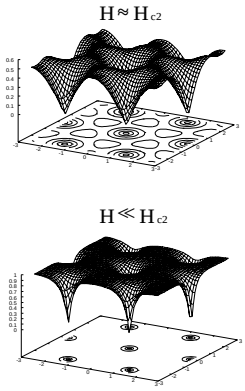

FIG.1: Real space profile of the pair potential obtained in our numerical calculation.

In this work we develop a method of calculating $\kappa(B)$ based on the quasi-classical theory of superconductivity which is valid in all fields from H_{c1} to H_{c2}. We calculate $\kappa(B)$ by fully taking account of the spatial dependence of the normal Green's function, that was neglected in the previous studies based on the Brandt-Pesch-Tewordt method. Then, we discuss the possibility of using $\kappa(B)$ as a probe of the pair potential symmetry.

[1] Kasahara *et al*., Phys. Rev. Lett. 96 (2006) 247004 and earlier references therein.
[2] C. Kubert and P. J. Hirschfeld, Phys. Rev. Lett. 96 (2006) 247004.
[3] I. Vekhter and A. Houghton, Phys. Rev. Lett. 83 (1999) 4626.

P-84 Thermal expansion measurement under pressure on UGe_2

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UGe_2 is a ferromagnet which shows pressure-induced superconductivity in the pressure range between ~10 kbar and ~16 kbar within the ferromagnetic state [1]. The Curie temperature T_C of about 53 K at ambient pressure decreases monotonically with pressure and is suppressed to zero temperature near P_C (~16 kbar) at which the superconductivity seems to vanish simultaneously. In addition to these phase transitions, a week anomaly corresponding to a certain phase transition or crossover was observed within a ferromagnetic phase at T_X (~30 K at ambient pressure). This characteristic temperature T_X also decreases with increasing pressure and suddenly disappears at P_X (~12 kbar). Since a maximum superconducting transition temperature (T_{SC}~0.7 K) is observed at around P_X, we conjecture that fluctuations relevant to this anomaly at T_X may play an essential role in the mechanism of the superconductivity.

Pfleiderer *et al*. provided evidence that the transition at P_X and P_C is of the first order by abrupt changes of an ordered ferromagnetic moment in the limit of zero field at 2.3 K [2]. If so, it is expected that there exists a critical end point. To obtain a pressure-temperature phase diagram, we measured the thermal expansion (by means of strain gauge method) and ac magnetic susceptibility under pressure, particularly concentrating on a temperature region around P_X.

[1] S.Saxena *et al*. Nature (London) **406**, 587 (2000).
[2] C. Pfleiderer *et al*. Phys. Rev. Lett. **30**, 147005 (2002).

P-85 Granular superconductivity in the $Sr_3Ru_2O_7$ region of Sr_2RuO_4-$Sr_3Ru_2O_7$ eutectic crystals

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We report superconducting properties of Sr_2RuO_4-$Sr_3Ru_2O_7$ eutectic crystals [1], consisting of the spin-triplet superconductor Sr_2RuO_4 and the metamagnetic normal metal $Sr_3Ru_2O_7$. AC susceptibility measurements reveal two superconducting transitions occurring in the $Sr_3Ru_2O_7$ region of the eutectic crystals, as shown in Fig. 1 [2]. The volume fraction of superconducting screening reaches essentially 100% at low AC fields, but is severely suppressed by AC fields of less than 1 Oe, much weaker than $H_{c2\,//c}(0)$ =750 Oe of Sr_2RuO_4. The presence of the two transitions and the much stronger sensitivity to AC fields than to DC fields suggest the presence of small superconducting grains in the $Sr_3Ru_2O_7$ region connected by a proximity network. We show calculations based on a granular superconductor model, which well reproduces the observed behavior. We discuss possible origins of the granular superconductivity in the eutectic $Sr_3Ru_2O_7$ region based on the parameters extracted from the model calculations.

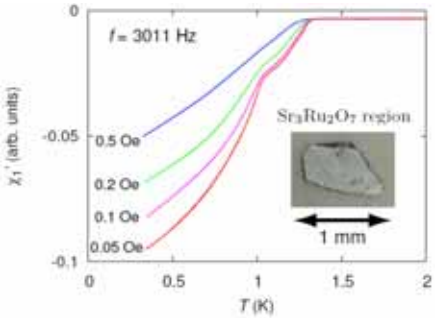

FIG. 1: Temperature dependence of the real part of the AC susceptibility at various fields. Numbers labeling the curves are AC field amplitude in Oe-rms.

[1] R. Fittipaldi *et al*., J. Cryst. Growth **282**, (2005) 152. [2] S. Kittaka *et al*., cond-mat/0607151.

P-86 High quality single crystal growth of unconventional *f*-electron superconductors

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In the strongly correlated ***f*** electron systems, the quality of sample is essential to reveal the anomalous low temperature behavior, especially, anisotropic superconductivity. For the investigations of those compounds, we have developed many technique of single crystal growth and purification of raw materials and compounds. Especially, our group succeeded to purify the uranium metal and growing single crystals of UPd_2Al_3, UPt_3, URu_2Si_2, UIr *etc*.. Furthermore, we have applied our technique to the investigation of the rare earth and the trans-uranium compounds and have succeeded to grow a single crystal of $PuRhGa_5$ which has a high superconducting transition temperature (T_{SC} = 8.0 K). These accumulations of the experiences to grow a high quality single crystal allow us to find new physical properties in ***f*** electron system.

Recently, we succeeded to grow a high quality single crystal of URu_2Si_2 compared to previous one which residual resistivity ratio is about 255. We measured the electrical resistivity, specific heat and magnetic properties by using the crystal for the **revaluation** of low temperature properties. The low the temperature behavior of the high quality sample is significantly different from those of reported works.

P-87 Momentum Transfer Dependence of Raman Spectra of Spin-triplet Superconductor Sr_2RuO_4

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We discuss the dependence of the electronic Raman spectra of the quasi-two dimensional spin-triplet superconductor Sr_2RuO_4[1] on the momentum transfer q between the incident and scattered light. Recently, we proposed a theory of the Raman spectra of p-wave pairing state with the k_x+ik_y and the $\sin k_x+i\sin k_y$[2] symmetry, which have been proposed as candidates for Sr_2RuO_4. The numerical results have shown that the Raman scattering is a useful tool to detect the gap anisotropy and a massive order parameter collective mode, which leads to the identification of the pairing symmetry of Sr_2RuO_4. However, we have not considered the finite momentum transfer in the scattering process. Since the coherence length of Sr_2RuO_4 is much larger than that of the high-T_c superconductors, the energy shift $v_F \cdot q$ is of the same order as the energy gap Δ in contrast to the high-T_c superconductors[3]. For more general discussion, the effect of the momentum transfer should be taken into account.

In this work, we present numerical results of the Raman spectra on the k_x+ik_y and the $\sin k_x+i\sin k_y$ states at the finite momentum transfer.

[1] A. P. Mackenzie and Y. Maeno, Rev. Mod. Phys. 75 (2003) 657.
[2] K. Miyake, and O. Narikiyo, Phys. Rev. Lett. 83 (1999) 1423.
[3] T.P. Devereaux and D. Einzel, Phys. Rev. B 51 (1995) 16336.

P-88 **Possible Existence of the Odd-Frequency Superconductivity**

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We investigate a possible realization of the odd-frequency superconductivity (odd-SC), whose gap function is odd in frequency. It is revealed that, for the odd-SC, the ferromagnetic fluctuation enhances the instability of *even*-parity (e.g., *s*-, *d*-wave) *triplet* pairing, and the antiferromagnetic one enhances that of *odd*-parity (e.g., *p*-, *f*-wave) *singlet* pairing. Strongly-retarded interactions are the necessary conditions that the odd-SC prevails over the conventional even-frequency superconductivity (even-SC). Whether the odd-SC practically realize depends on the details of the pairing interaction or the Fermi surface.

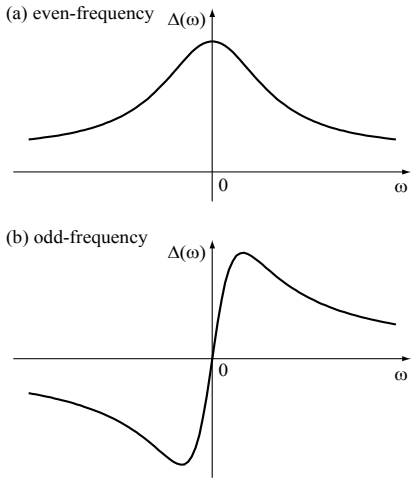

FIG.1: Schematic drawing of the superconducting gap, Δ(ω), as a function of frequency, ω, for (a) even- and (b) odd-frequency superconductivity.

In order to investigated a concrete possibility of the odd-SC, we solve the gap equation with the practical interactions for the heavy fermion Ce-compounds. The ***p*-wave *singlet* odd-SC** is realized in the vicinity of the antiferromagnetic quantum critical point on both the paramagnetic and the antiferromagnetic sides. The calculated gap function has no gap on the Fermi surface, so that the physical quantities show gapless behaviors. This can give a qualitative understanding of the gapless behaviors of NQR relaxation rate and specific heat on $CeCu_2Si_2$ and $CeRhIn_5$.

Also, we discuss the anomalous Meissner effects, which is a specific characteristic of the odd-SC.

[1] Y. Fuseya, H. Kohno and K. Miyake: J. Phys. Soc. Jpn. **72** (2003) 2914.

P-89 **Magnetic Relaxation and Minority Spin Condensate in Spin-Polarized Superfluid ^{3}He A_1**

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[2] *Serin Physics Laboratory, Rutgers University, Piscataway NJ 08854 USA*

The spin relaxation phenomenon in superfluid ^{3}He A_1 phase is studied using a newly constructed magnetic fountain pressure cell in which a large reservoir is connected to a small detector chamber through two channels of height 18 μm [1]. Super-spin current is induced by externally applied magnetic field. Measurements of the relaxation of the concomitant fountain pressure are carried out under a variety of conditions including pressure, temperature, static field and ^{4}He (5 monolayers) coverage. The relaxation of fountain pressure reflects that of the spin density in A_1 phase. The observed relaxation time τ varies from less than 1 s near T_{c2} to about 80 s near T_{c1}. Near T_{c2}, the observed relaxation rate may be described by a power law dependence on reduced temperature. The ^{4}He coverage does not alter the measured spin relaxation rate. This observation supports the interpretation that the relaxation rate is a bulk liquid effect. To our knowledge, there is no theory which predicts such increase in relaxation rate over a relatively large temperature range near T_{c2}. A possible interpretation is given in terms of Leggett-Takagi mechanism of intrinsic spin relaxation arising from small but increasing presence of minority spin pair condensate in A_1 phase as T_{c2} is approached.

[1] A. Yamaguchi, S. Kobayashi, H. Ishimoto and H. Kojima, to be published in *Nature*.

P-90 AC Susceptibility Experiments of Ferromagnetic Superconductor UGe_2 Sensitive to Pressure Homogeneity

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Since an observation of unusual coexistence of superconductivity with ferromagnetism (FM) in a narrow pressure range between ~9 to ~16 kbar, UGe_2 has attracted much attention [1]. The Curie temperature T_C of 52 K at ambient pressure monotonically decreases with increasing pressure, and finally collapses to zero at around a ferromagnetic critical pressure P_C ~16 kbar. It is now generally accepted that there is a crossover or phase transition within a FM phase: A characteristic temperature separating the FM phase into two regions, called T_X, shows a similar pressure dependence to T_C; T_X is about 30 K at ambient pressure and suddenly disappears at around P_X ~12 kbar. Since a superconducting transition temperature T_{SC} exhibits a maximum in the vicinity of P_X, it is assumed that the presence of P_X plays an important role in the occurrence of superconductivity.

We report the superconducting phase diagram investigated by ac magnetic susceptibility measurement. Compared to a pressure-temperature phase diagram previously reported by some of the present authors [2], we found that the superconductivity appears in a very narrow pressure region at aroud P_X. This is possibly ascribed to the difference in the pressure transmitting medium used; Daphne oil in the present study shows better homogeneity than Fluorinert used in Ref.[2]. We will discuss the correlation of superconductivity with the ferromagnetism based on this revised phase diagram.

[1] S. S. Saxena *et al*., Nature (London) **406** (2000) 587.
[2] H. Nakane *et al*., J. Phys. Soc. Jpn. **74** (2005) 855.

P-91 Anomalous Flux-Jumps in the Superconductivity State of Sr_2RuO_4

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The layered ruthenate Sr_2RuO_4 is evidenced to be a spin-triplet superconductor with two-component order parameter $\boldsymbol{d(k)}=\boldsymbol{z}\Delta_0(k_x \pm ik_y)$, from the experimental results on μSR[1] and NMR[2] measurements. In order to investigate the "chiral"-superconducting properties as well as the pinning characteristics, detailed magnetization measurements of the single crystalline Sr_2RuO_4 have been performed in the field direction parallel to the [001] axis by means of a capacitive Faraday force magnetometer.

Figure 1 shows the isothermal magnetization curves of Sr_2RuO_4 at 0.09 K. Anomalous successive flux-jumps of the hysteretic magnetization are observed around zero field. The flux-jumps are observed at temperatures up to about 0.3 K. Possible origins are discussed from the viewpoints of the pairing symmetry and the topological change in the vortex lattice configuration.

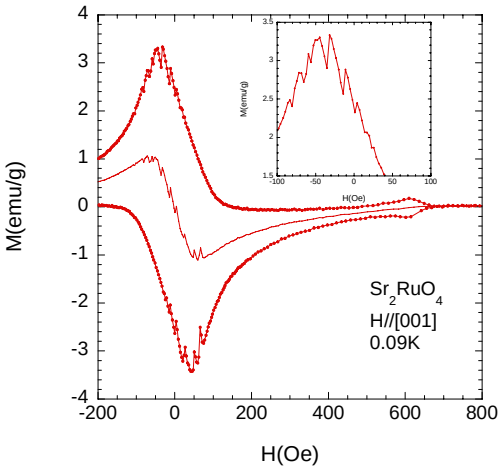

Fig.1: Magnetization curves in Sr_2RuO_4 at 0.09 K. A thin solid line is the equilibrium magnetization obtained by averaging the increasing- and decreasing-field data. The inset shows anomalous successive flux-jumps observed around zero field.

[1] G. M. Luke *et al*., Nature (London) **394** (1998) 558.
[2] K. Ishida *et al*., Nature (London) **396** (1998) 658.

P-92 Analytical Formulation of the Local Density of States around a Vortex Core in Unconventional Superconductors

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On the basis of the quasiclassical theory of superconductivity, we obtain a formula for the local density of state (LDOS) around a vortex core of superconductors with anisotropic pair-potential and anisotropic Fermi surface in arbitrary directions of magnetic fields. Earlier results on the LDOS of d-wave superconductors and $NbSe_2$ are naturally interpreted within our theory geometrically; the region with high intensity of the LDOS observed in numerical calculations turns out to the enveloping curve of the trajectory of Andreev bound states [1]. We show the LDOS in d-wave superconductors with simple cubic tight-binding model as examples with a strong anisotropic Fermi surface and a noncentrosymmetric superconductor such as $CePt_3Si$ without mirror symmetry about the ab plane [2](FIG. 1).

[1] Y. Nagai *et al*., J. Phys. Soc. Jpn. **75** (2006) 104701.
[2] Y. Nagai *et al*., J. Phys. Soc. Jpn. **75** (2006) 043706.

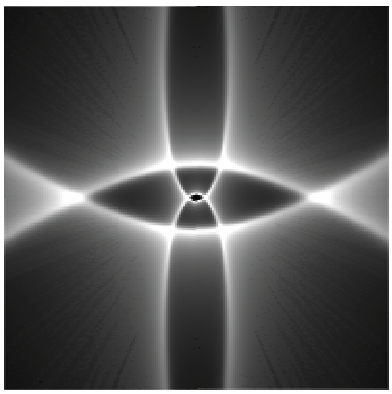

FIG.1: Distribution of the local density of the states around a single vortex perpendicular to the c axis.

P-93 Elastic Moduli of Sr_2RuO_4 in Magnetic Field

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A superclean system of Sr_2RuO_4 (SRO) is a strong candidate for a spin-triplet superconductor. There has attracted a growing interest in ultrasonic measurement for the superconducting state of SRO in magnetic fields as a crucial test of triplet superconductivity.

We have measured the elastic moduli C_{11}, $(C_{11}-C_{12})/2$, C_{44} and C_{66} in the field along the *a* axis. As shown in Fig. 1, we pay an attention to a step in the field dependence of C_{66} at the upper critical fields is an evidence of the triplet superconductivity with two-dimensional order parameter. Moreover, we have also explored the field-induced multi phases with the different order parameters as is reported by Tenya *et al* [1]. Improving the sensitivity of our ultrasonic measurement will make possible to conform the existence of the new phase.

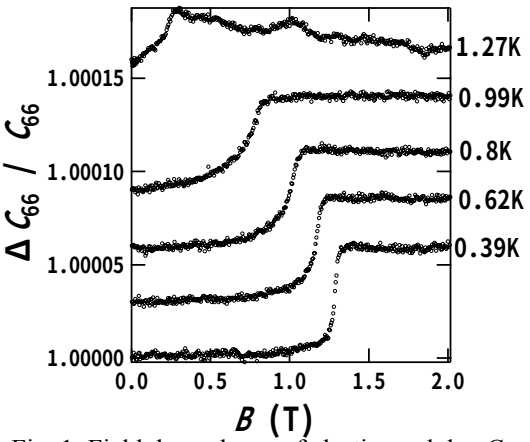

Fig. 1: Field dependence of elastic modulus C_{66}

P-94 Little-parks oscillation of spin-triplet superconductor Sr_2RuO_4

I. Kawasaki,[1] A. Ishii,[1] Y. Shimizu,[1] K. Tenya,[1] H. Amitsuka,[1] K. Inagaki,[2] S. Tanda,[2]
K. Deguchi[3] and Y. Maeno[4,5]

[1]*Department of Physics, Hokkaido University, Sapporo 060-0810, Japan*
[2]*Department of Applied Physics, Hokkaido University, Sapporo 060-08628, Japan*
[3]*Department of Physics, Nagoya University, Nagoya 464-8602, Japan*
[4]*Department of Physics, Kyoto University, Kyoto 606-8502, Japan*
[5]*International Innovation Center, Kyoto University, Kyoto 606-8501, Japan*

Sr_2RuO_4 is the first layered perovskite superconducting oxide without CuO_2 plane. Recent NMR Knight-shift and μSR measurements[1,2] have revealed that the spin-triplet superconductivity with the order-parameter $\boldsymbol{d}(\boldsymbol{k}) = \boldsymbol{d}_0 (k_x \pm ik_y)\boldsymbol{z}$.

In order to investigate the unconventional superconductivity we have perform the measurements of Little-Parks(L-P) oscillation by means of ac resistivity measurements; The observation of the L-P oscillation in unconventional superconductors is succeeded only in the high T_c cuprates $YBa_2Cu_3O_{7-\delta}$[3]. The single crystalline sample with T_c = 1.42K was prepared by a floating-zone method and fabricated into film-like shape(thickness 2-3μm) with 4-μm^2 plaquette by using focused ion beam, as shown in Fig. 1.

[1] K. Ishida. Luke *et al*., Nature. **396** (1998) 658.
[2] G. M. Luke *et al*., Nature. **394** (1998) 558.
[3] P. L. Gammel *et al*., Phys. Rev. B **41** (1990) 2593.

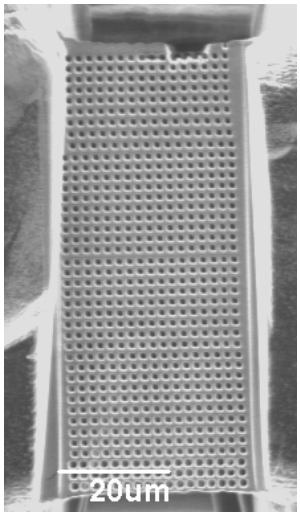

Fig1. Micrograph of the patterned film like shape Sr_2RuO_4 used in this mesurement.

P-95 **Reinvestigation of the low-field *H-T* phase diagram of Sr_2RuO_4**

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There is experimental evidence that the superconductivity of Sr_2RuO_4 at $H = 0$ is characterized by the spin-triplet order parameter $\boldsymbol{d} = \Delta_0 \boldsymbol{z}\ (k_x + ik_y)$, pointing along the *c* axis. From NQR Knight shift experiments it was suggested that the ***d*** vector may flip perpendicular to the *c* axis if one applies a small finite field (less than 200 G) [1]. Therefore it is desirable to find experimental evidence for the mentioned ***d***-vector rotation by a precise reinvestigation of the low-field part of the *H-T* phase diagram for *H* parallel to the *c* axis. The currently known phase diagram obtained by specific-heat and AC-susceptibility measurements is shown in Fig. 1 [2, 3].

We will present AC-susceptibility data of Sr_2RuO_4 with $H \parallel c$ axis. Before the measurement the single crystalline sample was cut to remove the 3 K phase contained in the crystal.

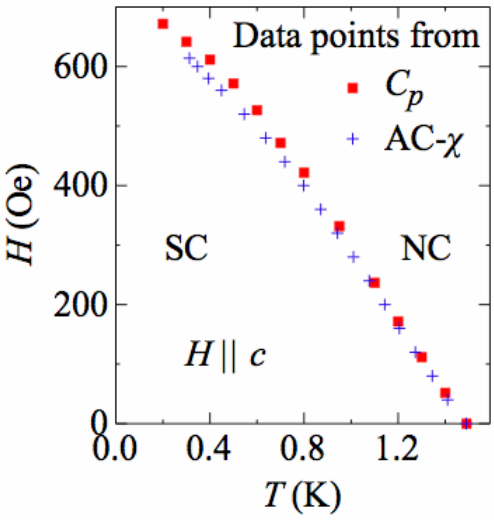

FIG. 1: *H-T* phase diagram of Sr_2RuO_4 for $H \parallel c$-axis.

[1] H. Murakawa *et al*., Phys. Rev. Let. **93** (2004) 167004.
[2] K. Deguchi *et al*., J. Phys. Soc. Jpn. **73** (2004) 1313.
[3] Z.Q. Mao *et al*., Phys. Rev. B **60** (1999) 610.

P-96 Effects of uni-axial pressure on superconductivity in eutectic crystals containing Sr_2RuO_4

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R. Fittipaldi,[2] A. Vecchione[2] and J. Hooper[3]

[1]*Department of Physics, Kyoto University, Kyoto 606-8502, Japan*
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[3]*Department of Physics, Tulane University, New Orleans, Louisiana 70118, USA*

The layered perovskite Sr_2RuO_4 is believed to be a spin-triplet superconductor with an ideal T_C of 1.5 K. Its eutectic systems include Sr_2RuO_4-Ru and Sr_2RuO_4-$Sr_3Ru_2O_7$ [1]. Sr_2RuO_4-Ru exhibits interface superconductivity with an enhanced T_C of about 3 K, known as the 3-K phase. We have found that Sr_2RuO_4-$Sr_3Ru_2O_7$ also exhibits surface superconductivity with an enhanced T_C and shows rather strong dependence of uni-axial pressure on the surface superconductivity (Fig. 1), similar to Sr_2RuO_4-Ru (3-K phase). Possible origins of the surface superconductivity will be discussed.

Another aspect of superconductivity in eutectic Sr_2RuO_4-$Sr_3Ru_2O_7$ is that the $Sr_3Ru_2O_7$ region exhibits superconductivity very sensitive to applied magnetic fields. Apparently, such behaviour can be well modelled as a superconducting network in granular superconductors [2]. We have also investigated the effect of uni-axial pressure on the superconductivity occurring in the $Sr_3Ru_2O_7$ region to obtain an insight into its origin.

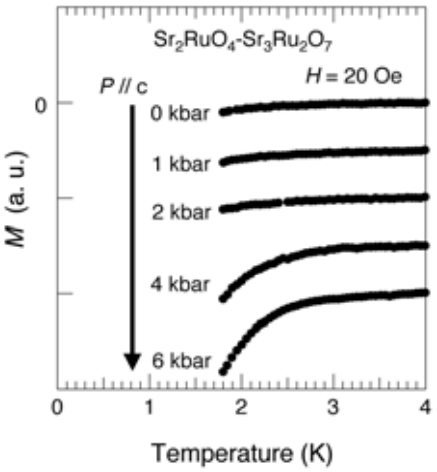

FIG.1: Diamagnetic magnetization of Sr_2RuO_4-$Sr_3Ru_2O_7$ at various pressures along the *c*-axis. Traces are offset.

[1] R. Fittipaldi *et al*., J. Cryst. Growth **282**, (2005) 152.
[2] S. Kittaka *et al*., cond-mat/0607151

P-97 Neel State Induced by the Four-Spin Exchange Interactions in S=1/2 Three-Leg XXZ Spin Ladder

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We investigate the S=1/2 three-leg spin ladder with 4-spin exchange interactions in the strong rung coupling limit. We use the degenerate perturbation theory to find the ground state of this model as a function of J_1 and J_4, where J_1 is the leg coupling and J_4 is the 4-spin exchange interaction coupling. We introduce the XXZ type anisotropy for the rung and J_1 couplings. In usual cases, the Neel ground state is realized when the XXZ anisotropy is Ising-like, while the Tomonaga-Luttinger-like spin fluid (TL-SF) state is realized when the XXZ anisotropy is XY-like. Contrary to this common sense, we found that the Neel state becomes the ground state even if the XXZ anisotropy XY-like in some parameter regions. This phase is induced by the effect of 4-spin interactions. We also found that the TL-SF state can become the ground state even when the XXZ anisotropy is XY-like in some parameter regions.

P-98 Possible Ground States of Metal-Halide Ladders

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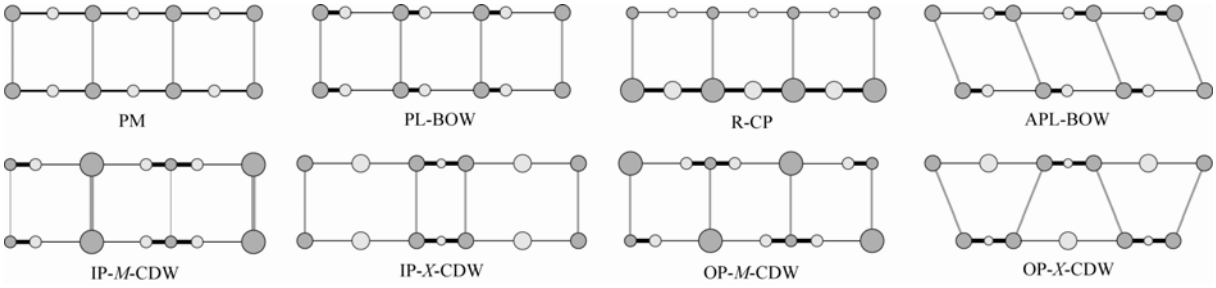
Motivated by newly synthesized ladder-shaped platinum-halide family compounds, $(C_8H_6N_4)[Pt(C_2H_8N_2)X]_2X(ClO_4)_3 \cdot H_2O$ (X=Cl, Br) and $(C_{10}H_8N_2)[Pt(C_4H_{13}N_3)Br]_2Br_4 \cdot 2H_2O$, we investigate the ground-state properties of a relevant two-band extended Peierls-Hubbard model [1]. Based on a symmetry argument, we systematically reveal possible charge- or spin-ordered states. Numerical phase diagrams demonstrate a variety of competing Peierls and Mott insulators with particular emphasis on the transition between two types of mixed-valent state of Pt^{II} and Pt^{IV} driven by varying interchain hopping integrals and Coulomb interactions.



[1] K. Funase and S. Yamamoto, J. Phys. Soc. Jpn. **75** (2006) 04471.

P-99 Phase Diagram of Inverse Perovskite Ising Antiferromagnet

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We study thermodynamic properties of the antiferromagnetic Ising model on the inverse perovskite lattice by Monte Carlo simulations. Though the Ising model is simple, effects of frustration offer a good starting point of other realistic analyses. The inverse perovskite lattice is composed of corner-sharing octahedra shown in the figure, where three-dimensional geometrical frustration exists in terms of the magnetic interaction. The system with the nearest neighbor interactions alone does not exhibit any phase transition, yielding the residual entropy at zero temperature. We study effects of external magnetic fields and an anisotropy in the interactions (J, $J_\perp$), and obtain the phase diagram in a wide range of parameters. Introducing these perturbations which lift the macroscopic degeneracy in the ground state leads to a rich structure with a finite-temperature transition to a ferrimagnetic state and to a partially-disordered antiferromagnetic state with the dimensionality reduction. As a result, the unperturbed simplest case turns out to be at a peculiar critical point. This point drags surrounding critical regions at nonzero temperatures into absolute zero. This character is not seen in other frustrated structures such as face-centered cubic and pyrochlore. The dimensionality reduction as well as the suppressed critical temperature to zero may offer an intriguing quantum effect if realistic quantum spins are considered.

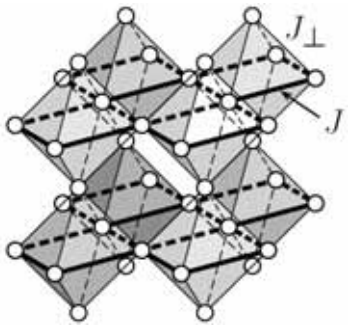

Fig: Inverse perovskite lattice structure. J and $J_\perp$ are the anisotropic interactions.

P-100 Entanglement Entropy of Quantum Spin Liquids: Localized Effective Spins on Edges

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Recently, there has been several tries to distinguish quantum liquids which can not be characterized by classical order parameters, or by the symmetry breaking based on the Ginzburg-Landau theory. Some of interesting phases can be understood as topological ordered phases, such as quantum Hall states, Haldane phase of integer spins, quantum dimers, polyacetylene, and so on. The non-locality of the quantum entanglement of the ground state is essential in this topological ordered phases.
On the other hand, entanglement entropy is defined in the field of quantum information physics to measure possible resources to perform quantum operations. It reflects how much the quantum state is entangled. Recently, it has been recognized that this entanglement entropy is useful to characterize the quantum liquids globally in the systems with finite excitation gap. It is natural to think the entanglement entropy as a global topological order parameter.
Also, this entanglement entropy reveals the bulk-edge correspondence which implies inherent characteristics of topological ordered phase. The entanglement entropy calculated in the bulk is related to the edge states which emerges in the system with boundaries. To be more precise, entanglement entropy of the bulk takes non-trivial value reflecting the existence of the edge states[1].
In our works, the entanglement entropy is evaluated numerically for several phases of S=1/2 dimerized Heisenberg spin chain, and S=1 XXZ spin chain. Further more, we also discuss the entanglement entropy of the valence-bond solid (VBS) state by using the extended transfer matrix technique[2].

[1] S. Ryu and Y. Hatsugai, Phys. Rev. B73, 245115 (2006)
[2] T. Hirano and Y. Hatsugai, unpublished (2006)

P-101 Quantum Phase Transition in 3-Leg Spin Tube

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An S=1/2 three-leg antiferromagnetic spin nanotube is investigated using the DMRG method and the level spectroscopy analysis combined with the numerical exact diagonalization. When the three rung couplings (Jr) are equivalent, it is known that the system has a spin gap. In this work, we discuss that as one of the three rung exchanges (Jr') varies, a quantum phase transition occurs at a critical value of the varied rung exchange, and then the system is in a gapless Tomonaga-Luttinger-liquid phase. A preliminary ground-state phase diagram containing this phase transition (Fig.1) is presented.

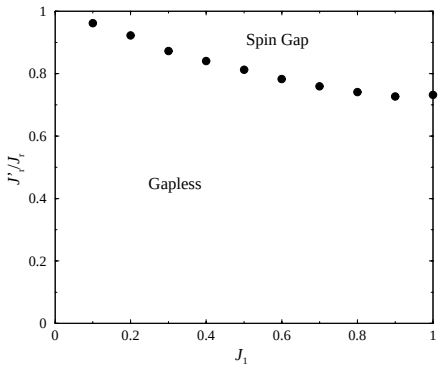

FIG.1: Phase diagram of the S=1/2 quantum spin system on the isosceles triangle tube.

P-102 Phase transition and Universality class of spin ladder systems with four-spin exchange

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S=1/2 quantum-spin two-leg ladder systems have been studied in relation with high temperature superconductivity, Haldane's conjecture, and the spin-orbital model. However, there are relatively few numerical studies on universality class of phase transitions. One of the difficult points is that often these phase transitions belong to infinite dimensional type, therefore there appear logarithmic corrections.

We have studied S=1/2 two-leg ladder XXZ spin model with two body interaction terms in ref. [1]. Next, with four-spin exchange terms, we have studied universality class of S=1/2 spin ladder in refs. [2] and ref [3]. We have found that the phase transition belongs to the central charge c=3/2 type in conformal field theory (CFT) language, after eliminating logarithmic corrections.

Recently, we are studying S=1/2 quantum-spin two-leg ladder systems inrelation with the spin-orbital model. At special point, this model has an SU(4) symmetry, In general couplings, we have found that there are the phase transition lines with the c=3/2 CFT which crossover to the first order transition.

[1] K. Hijiii and K. Nomura and A. Kitazawa, Phys. Rev. B, 72, 014449 (2005)
[2] K. Hijiii and K. Nomura, Phys. Rev. B, 65, 104413 (2002)
[3] K. Hijii, S. Qin and K. Nomura, Phys Rev. B, 68, 134403 (2003)

P-103
Quantum Ground State of *S*=1 *Kagomé* Antiferromagnet *m*-MPYNN·BF_4

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As well as quantum fluids, we are interested in low-dimensional quantum spin systems where quantum fluctuation plays a major role and exotic quantum ground states are realized. As 2D solid ^{3}He systems, organic radical magnets realize ideal Heisenberg spin systems, owing to the orbital quenching, and sufficiently clean systems by easiness of the synthesis without magnetic impurities. The organic magnet *m*-MPYNN·BF_4 has 2D organic layers separated by nonmagnetic anions and solvents. In each organic layer, two *m*-$MPYNN^+$ radicals with S=1/2, arranged on each side of a 2D triangular lattice, form S=1 dimers sufficiently below the temperature corresponding to the ferromagnetic interaction $2J$ = 23 K, and then realize a S=1 *Kagomé* lattice with the antiferromagnetic interaction $2J_0$ = −3 K. Measurements of magnetic susceptibility and magnetization revealed the nonmagnetic ground state with a spin gap of about 0.2 K in zero field. Below 0.1 K, we also observed magnetization plateaus at 1/2 and 3/4 of the saturation magnetization (Fig. 1), which are characteristic of a spin-gapped system.

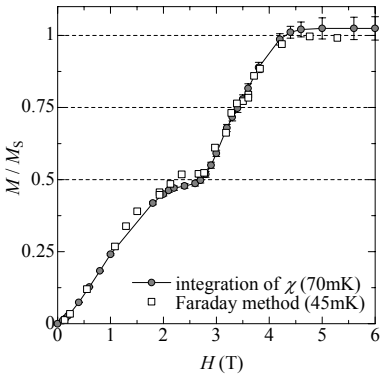

FIG. 1: Magneization curve of *m*-MPYNN·BF_4. Plateaus appear at 1/2 and 3/4 of the saturation magnetization.

P-104 Single Crystal Study of $NiGa_2S_4$: Frustrated Heisenberg $S = 1$ Spins on 2D Triangular Lattice

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We have succeeded in growing large single crystals of $NiGa_2S_4$ [1], a rare example of an $S = 1$ two-dimensional triangular antiferromagnet. Thermodynamic measurements have confirmed the absence of long-range order or conventional spin glass ordering, consistent with the previous ploycrystalline results [1]. The T^2 dependent specific heat below 10 K, indicating linearly dispersive modes in two dimension, is insensive to magnetic fields even at 7 T (Fig. 1). Futhermore, detailed magnetic measurements have revealed that $S = 1$ spins on the triangular lattice are of *Heisenberg* type with weak easy-plane anisotropy. The susceptibility is almost isotropic but has an anomaly around 10 K for fields only along the in-plane (*ab*) directions (Fig. 1, inset), suggesting the presence of weak easy-plane-type anisotropy. We will discuss a possible ground state of $NiGa_2S_4$.

[1] S. Nakatsuji *et al.*, *Science* **309**, 1697 (2005)

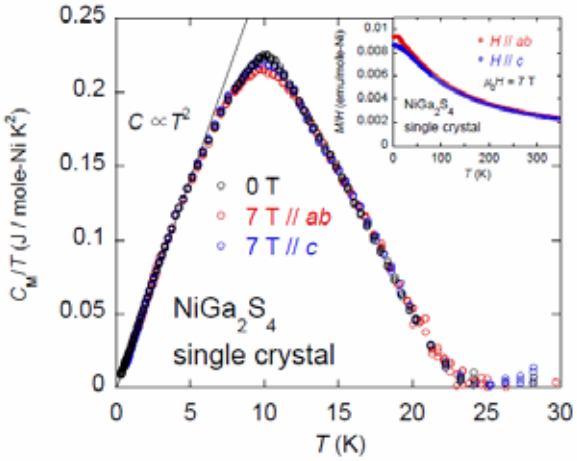

FIG.1: Temperature dependence of magnetic specific heat of $NiGa_2S_4$ single crystals under magnetic fields along both the in-plane (*ab*) and *c* directions. Inset shows the temperature dependence of susceptibility.

P-105 Magnetization curve of two-dimensional anti-ferromagnetic solid ^{3}He in high magnetic fields

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A low-density solid ^{3}He film adsorbed on graphite surface is one of the most ideal two-dimensional (2D) quantum spin systems. The so called 4/7 commensurate phase in the second layer is a highly frustrated magnet with anti-ferromagnetic triangular lattice and competing multiple spin exchanges. The ground state is believed to be a gapless spin liquid [1],[2]. The magnetization curve obtained from a double gradient Faraday method suggests the existence of plateau and no saturation even at 1 mK and 10 T. Here we report a low field portion of magnetization curve investigated with NMR up to about 2.5 T.

[1] K. Ishida *et al.*, Phys. Rev. Lett. **79**, 3451 (1997)

[2] R.Masutomi *et al.*, Phys. Rev. Lett. **92**, 025301 (2004).

P-106 Nonmagnetic / Magnetic Impurity Effects on the Spin Disordered State in $NiGa_2S_4$

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Recently, a quasi-two-dimensional (2D) $S = 1$ triangular antiferromagnet (AFM) $NiGa_2S_4$ has been discovered as the first example of a bulk low-spin AFM on an exact triangular lattice [1]. Despite antiferromagnetic interactions of 80 K, neither long-range order nor conventional spin glass ordering has been detected down to 0.35 K. Instead, various measurements show the formation of a gapless spin disordered state at low temperatures. With nonmagnetic Zn substitution, the gapless state is found to be robust, showing the constant susceptibility as $T \rightarrow 0$, the T^2-dependent specific heat, and their scaling behavior with the Weiss temperature (FIG.1). This suggests the existence of the gapless linearly dispersive mode due to a novel symmetry breaking in 2D [2]. Here, we present the fundamental features of $NiGa_2S_4$ as well as recent results of nonmagnetic / magnetic impurity effects.

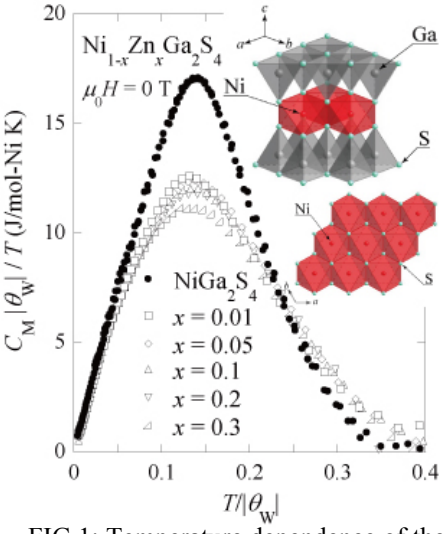

FIG.1: Temperature dependence of the magnetic specific heat in the Zn substituted compounds and the crystal structure of $NiGa_2S_4$.

[1] S. Nakatsuji, Y. Nambu, H. Tonomura, O. Sakai, S. Jonas, C. Broholm, H. Tsunetsugu, Y. Qiu and Y. Maeno, *Science* **309**, 1697 (2005).

[2] Y. Nambu, S. Nakatsuji and Y. Maeno, *J. Phys. Soc. Jpn.* **75**, 043711 (2006).

P-107 Nontrivial quantized Berry phases for spin liquids in one-dimensional t-J model with a few electrons

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We study the Berry phase in one-dimensional t-J model with a few electrons. The quantized Berry phase as a local order parameter of quantum liquids is expected to characterize a topological order or quantum order as demonstrated in Ref. [1] where the Berry phase is quantized as trivial or non-trivial value, i.e., 0 or π, due to some anti-unitary symmetry. It characterizes the configuration of localized spin singlet. We apply the scheme to calculate the quantized Berry phase in the t-J model as a strongly correlated electron system.

One-dimensional t-J model with a few electrons gives a simplest realization of itinerating singlets when the exchange energy J is large. Although the charge excitation is gapless, the spin gap is finite. Then we can calculate the Berry phase by treating low energy states as a degenerated multiplet. It is found that the quantized Berry phase gained through local spin twists becomes uniform and nontrivial when the number of electrons N=4n+2, with n being an integer.

[1] Y. Hatsugai, J.Phys.Soc.Jap. 74 (2005) 1374, ibid 73 (2003) 2604, cond-mat/0603230 to appear in J. Phys. Soc. Jpn., cond-mat/0607024 to appear in J. Phys. C condensed matt.

P-108 Instability of Plaquette Valence-Bond Crystal Phase in the Planar Pyrochlore Electron System

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Strongly correlated electron systems on frustrated lattice have attracted much interest recently. Typical examples are the transition metal oxides LiV_2O_4 [1] and $Tl_2Ru_2O_7$ [2] with pyrochlore structure, where the heavy fermion behavior and the Mott transition without magnetic ordering are observed, respectively. These experimental findings stimulate theoretical investigations on the frustrated correlated electron systems. Among them, the Hubbard model on the planar pyrochlore lattice, which can be considered as a two-dimensional version of the pyrochlore lattice, has been investigated intensively [3]. In the system, it has been clarified that the plaquette valence-bond crystal (P-VBC) state is realized in the strong coupling (Heisenberg) limit[4]. Here by tuning the ratio of the nearest-neighbor hopping to the diagonal hopping and the electron-electron interaction systematically, we study the instability of the P-VBC phase to clarify the role of geometrical frustration in the system.

To this end, we make use of the path-integral renormalization group method [5]. We then discuss how the P-VBC state competes with the paramagnetic metallic state and the antiferromagnetically ordered state that is stabilized in the unfrustrated system.

[1] S. Kondo et al., Phys. Rev. Lett. **78** (1997) 3729.
[2] H. Sakai et al., J. Phys. Soc. Jpn. **71** (2002) 422.
[3] S. Fujimoto, Phys. Rev. Lett. **89** (2002) 226402.
[4] E. Runge and P. Fulde, Phys. Rev. B **70** (2004) 245113
[5] T. Kashima and M. Imada, J. Phys. Soc. Jpn. **70** (2001) 2287.

P-109 Spin Nematic State in S=1 Triangular Antiferromagnets

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Recently spin-liquid like state has been discovered in the triangular magnet, $NiGa_2S_4$ [1]. This material shows many unusual low-temperature properties and it is difficult to explain them consistently by ordinary mechanisms like magnetic ordering or spin-gap state. To understand the basic properties of this spin-liquid like, we proposed a scenario based on spin nematic state [2]. We employed an S=1 spin model on triangular lattice with bilinear-biquadratic interactions. We studied an antiferro nematic order phase with three-sublattice structure, and several physical quantities were examined. In this report, we will discuss the temperature dependence of the magnetic properties, in particular, the spin dynamics as well as spin quadrupole response.

[1] S. Nakatsuji *et al*, Science **309** (2005) 1697.
[2] H.Tsunetsugu *and* M. Arikawa, J. Phys. Soc. Jpn. **75** (2006) 083701.

P-110

^{69,71}Ga nuclear quadrupole resonance on quasi two dimensional frustrated triangular antiferromagnet $NiGa_2S_4$

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We performed ^{69,71}Ga nuclear quadrupole resonance (NQR) on the quasi two dimensional antiferromagnet $NiGa_2S_4$, which exhibits no long-range magnetic order down to 0.35 K from magnetic susceptibility, specific heat, and neutron diffraction measurements. NQR spectrum exhibits two peaks for each Ga isotope although $NiGa_2S_4$ has only one crystallographic site. One possible interpretation of the two-peak structure is that a tiny amount of sulfur deficiency induces a different local symmetry site. Nuclear spin-lattice relaxation rate $1/T_1$ was measured at both Ga sites and showed divergent behavior at around 10 K (Fig. 1).

A broad structureless spectrum was observed below 2 K, suggestive of the short-range ordering at low temperatures. Plausible magnetic state is discussed on the basis of the experimental results reported so far.

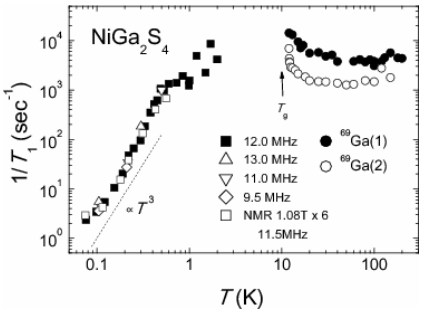

Fig.1: Nuclear spin-lattice relaxation rate $1/T_1$ measured at ^{69}Ga(1) and ^{69}Ga(2) sites above 10 K, and several frequencies below 2K.

[1] S. Nakatsuji *et al.*: Science. **309** (2005) 1697.

P-111 Metal-Insulator transition in the Hollandite vanadate, $K_2V_8O_{16}$

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The synthesis, structure and electromagnetic properties of $K_2V_8O_{16}$ hollandite are reported. In the crystal structure, the double chains of edge sharing VO_6 octahedra share corners with neighboring chains to form a V_8O_{16} stoichiometry framework that encloses large four-sided tunnels. The K^+ cations are located in the tunnels. Since the crystallographic site of vanadium atom is unique, $K_2V_8O_{16}$ is a mixed-valence compound. The formal oxidation of V is +3.75. We successfully obtained $K_2V_8O_{16}$ by a high pressure synthesis. In this compound, we observed a temperature-induced metal-insulator transition at around 170K for the first time [1]. Above the transition, the magnetic susceptibility is almost temperature independent, then rapidly drops at the transition and increases again at low temperature, obeying a Curie law below 50 K. Since the Curie constant is very small, the Curie tail could be due to impurity and/or defects. Therefore the reduction of magnetic susceptibility suggests the ground state is a spin-singlet. We also observed the structural change accompanied by a superstructure of $\sqrt{2}a \times \sqrt{2}a \times 2c$ below the transition. We propose a possible charge order model of vanadium ions below the transition [1].

We also investigated Ti-doping effect on the metal-insulator transition. Surprisingly the substitution of Ti for V raises the transition temperature. This significant rise of transition temperature may be understood as a negative chemical pressure effect caused by the Ti-substitution. The disorder effect on the electronic state from the Ti-substitution makes the transition broad and finally the transition smears out.

[1] M. Isobe *et al.*, J. Phys. Soc. Jpn. **75** (2006) 073801.

P-112 Ground state phase diagram of a ring-exchange model on the triangular lattice

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We investigated the ground state of a ring-exchange model on the triangular lattice, which may describe magnetism of the ^{3}He layers adsorbed on graphite. First we investigated a model with only four-spin ring exchange term in addition to the ordinary Heisenberg exchange term. We employed the mean field theory and found that various phases are stabilized according to the magnitudes of the interaction parameters and the external field. We also employed the spin wave theory to estimate the stability of the 120 degree structure. We fond that the softening of the spin wave leads to the ground state phase transition from the 120 degree structure to a ground state with six sublattices[1]. Next we examined the effects of five- and six-spin ring exchange terms by adding those terms assuming that $J_5/J_4=J_6/J_4=0.3$. We found that the five-spin term enhances the ferromagnetic character of the system strongly, but effect of the six-spin term is weak.

[1] C.Yasuda *et al*., J. Phys. Soc. Jpn. **75** (2006) 104705.

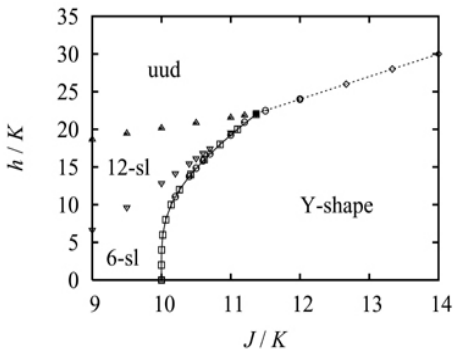

FIG.1: A part of the ground state phase diagram of the ring-exchange model with only four-spin term on the triangular lattice.

P-113 **Mott Insulator at Quarter Filling**

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We study quantum phase transitions of a two-dimensional extended Hubbard model at quarter filling with both onsite and intersite Coulomb repulsion (U and V respectively) in the strong correlated regime by using a cluster extension of dynamical mean field theory [1]. By interpolating the square and checkerboard lattice, effects of geometrical frustration on charge, as well as spin, are studied. In the regime of small frustration, the model shows a metal-insulator transition at a critical value of V which is always accompanied by charge ordering with corresponding antiferromagnetic ordering. At larger frustration, successive phase transitions are found first from a metal to a Mott insulator and then to a charge ordered insulator but without spin order with increasing value of V. As the frustration is even stronger, the insulating phase appears always without any charge and spin order. This novel insulating state is the direct consequence of the cooperation between the geometrical frustration, which suppress the orderings, and the strong intersite Coulomb interaction, which tends to stabilize an insulating state at quarter filling. The present insulator without spin and charge orders offers insight into insulating states in magnetite, Fe3O4 and LiV2O4 under pressure. To our knowledge, Mott insulator is extensively discussed at half filling [2] while at quarter filling, this is the first time to report [3].

[1] G. Kotliar, S. Y. Savrasov, G. Pallson, and G. Biroli, Phys. Rev. Lett. 87, 186401 (2001).
[2] M. Imada, A. Fujimori, and Y. Tokura, Rev. Mod. Phys. 70, 1039 (1998).
[3] Y. Z. Zhang, and Masatoshi Imada, unpublished.