International Symposium on Quantum Fluids and Solids - QFS2013

August 1st - 6th, 2013

Kunibiki Messe, Matsue, Japan

International Advisory and Program Committee:

Yuichi Okuda	(Tokyo Tech, Chair)
Vanderlei S. Bagnato	(São Paulo)
Sébastien Balibar	(Paris)
John Beamish	(Alberta)
Natalia G. Berloff	(Cambridge)
Moses H. W. Chan	(Penn State)
Franco Dalfovo	(Trento)
J. C. Séamus Davis	(Cornell)
Vladimir V. Dmitriev	(Kapitza)
Vladimir Eltsov	(Aalto)
Shaun Fisher	(Lancaster)
Hiroshi Fukuyama	(Tokyo)
Henri Godfrin	(Grenoble)
Andrei Golov	(Manchester)
Robert B. Hallock	(Amherst)
William P. Halperin	(Northwestern)
E. Susana Hernández	(Buenos Aires)
Wolfgang Ketterle	(MIT)
Eunseong Kim	(KAIST)
Kimitoshi Kono	(Riken)
Daniel Lathlop	(Maryland)
Yoonseok Lee	(Florida)
Paul Leiderer	(Konstanz)
Li Lu	(Beijing)
Jeevak Parpia	(Cornell)
Jukka Pekola	(Aalto)
George R. Pickett	(Lancaster)
Emil Polturak	(Technion)
James A. Sauls	(Northwestern)
John Saunders	(Royal Holloway)
Keiya Shiramama	(Keio)
Ladislav Skrbek	(Prague)
Peter Skyba	(Košice)
Nandini Trivedi	(Ohio)
Makoto Tsubota	(Osaka City)
Grigori Volovik	(Aalto)

Local Organizing Committee:

Yuichi Okuda	(Tokyo Tech, Chair)
Kimitoshi Kono	(Riken)
Hiroshi Fukuyama	(Tokyo)
Makoto Tsubota	(Osaka City)
Keiya Shiramama	(Keio)
Ryuji Nomura	(Tokyo Tech)
Yuki Kawaguchi	(Tokyo)

Scientific Programme Overview

Morning Sessions

	09:40–10:40		11:10–12:10	12:10–13:30
Thursday August 1	Opening ceremony & Quantum Fluids	Coffee	Quantum Fluids	Lunch
	09:00–10:40		11:10–12:10	12:10–13:30
Friday August 2	Quantum Turbulence	Coffee	Quantum Fluids	Lunch
Saturday August 3	Quantum Solids	Coffee	Quantum Fluids	Lunch
Sunday August 4	Excursion			
Monday August 5	Topological Quantum Phenomena	Coffee	Quantum Turbulence	Lunch
Tuesday August 6	Low Dimensional Systems	Coffee	QF and Particle Physics & Closing ceremony	

Afternoon Sessions

13:30–15:10		15:50–16:50	17:00–19:00	
Helium in Aerogel	Coffee	Other Topics	Poster Session 1	Thursday August 1
Quantum Gases	Coffee	Devices & Techniques	Poster Session 2	Friday August 2
Low Dimensional Systems	Coffee	Quantum Gases	Poster Session 3	Saturday August 3
Excursion				Sunday August 4
Exciton-Polariton	Coffee	Quantum Fluids & Solids	Poster Session 5	Monday August 5
				Tuesday August 6

Scientific Programme

Thursday August 1st

09:00		**Registration**	
09:40		**Opening Ceremony**	
Session 1.1: Quantum Fluids			**Chair: Shaun Fisher**
10:00	P1.1	Vladimir Eltsov	Experimental Signatures of Vortex Core Structures in Superfluid ^{3}He [**Plenary Talk**]
10:40		Coffee Break	
Session 1.1: Quantum Fluids			**Chair: Shaun Fisher**
11:10	O1.1	Paul Walmsley	Chiral Textures in Slabs of Superfluid ^{3}He-A
11:30	O1.2	Hiroki Ikegami	Direct Detection of Chirality in Superfluid ^{3}He-A
11:50	O1.3	Petri Heikkinen	Gravity Waves on the Surface of Topological Superfluid ^{3}He-B
12:10		Lunch	
Session 1.2: Helium in Aerogel			**Chair: Jeevak Parpia**
13:30	P1.2	Jim Sauls	Liquid ^{3}He in Random Media [**Plenary Talk**]
14:10	O1.4	Vladimir Dmitriev	Superfluid Phases of ^{3}He in "Ordered" Aerogel
14:30	O1.5	Johannes Pollanen	^{3}He in Aerogel: Engineering Superfluid States with Disorder
14:50	O1.6	Ryusuke Ikeda	Possible Phase Diagram of Superfluid ^{3}He in Highly Anisotropic Aerogel
15:10		Coffee Break	
Session 1.3: Other Topics			**Chair: Ryuji Nomura**
15:50	O1.7	Yuriy Bunkov	Direct Observation of a Majorana Quasiparticle Heat Capacity in ^{3}He
16:10	O1.8	Murat Tagirov	Magnon BEC in Antiferromagnets with Suhl-Nakamura Interaction
16:30	O1.9	André Strydom	Non-Fermi Liquid Behaviour in the Heavy-Fermion Kondo Lattice $Ce_2Rh_3Al_9$
17:00	PS1	**Poster Session 1:**	Quantum Fluids, Other Topics

Friday August 2nd

Session 2.1: Quantum Turbulence			**Chair: Yuri Sergeev**
09:00	P2.1	William Vinen	Quantum Turbulence: Aspects of Visualization and Homogeneous Turbulence [**Plenary Talk**]
09:40	O2.1	Ladik Skrbek	Investigation of Quantum Flows of ^{4}He by Visualization and Second Sound Attenuation
10:00	O2.2	Hideo Yano	Vortex Emission from Quantum Turbulence Generated in Superfluid ^{4}He
10:20	O2.3	Vanderlei Bagnato	Observation of Anomalous Momentum Distribution in a Sample of Turbulent BEC obtained by Free Expansion
10:40		Coffee Break	
Session 2.2: Quantum Fluids			**Chair: Kazushige Machida**
11:10	O2.4	Joshua Wiman	Superfluid Phases of ^{3}He in a Periodic Confined Geometry
11:30	O2.5	Andrew Zimmerman	Order Parameter Texture Transition in Superfluid ^{3}He-B in Aerogel
11:50	O2.6	Lev Melnikovsky	Parametrically Excited Coherent Roton Aggregates
12:10		Lunch	
Session 2.3: Quantum Gases			**Chair: Yusuke Kato**
13:30	P2.2	Yoshiro Takahashi	Quantum Magnetism of Cold Atoms in an Optical Lattice [**Plenary Talk**]
14:10	O2.7	Xiaoling Cui	Spin-Orbit Coupled Ultracold Atomic Gases
14:30	O2.8	Muneto Nitta	Vortex Molecules in Bose-Einstein Condensates
14:50	O2.9	Shunji Tsuchiya	The Higgs Amplitude Mode in a Superfluid of Dirac Fermions
15:10		Coffee Break	
Session 2.4: Devices and Techniques			**Chair: Reyer Jochemsen**
15:50	O2.10	Martial Defoort	Energy Dissipation in Nano-electro-mechanical Devices at Millikelvin Temperatures
16:10	O2.11	Yutaka Sasaki	Developing Magnetic Resonance Spectroscopic Imaging ULTMRSI to Study Inhomogeneous Texture in Superfluid ^{3}He
16:30	O2.12	Tohru Hata	Development and Comparison of Two Different Types of Dry Dilution Refrigerator
17:00	PS2	**Poster Session 2:**	Vortices & Turbulence, Devices, Techniques

Saturday August 3rd

Session 3.1: Quantum Solids		**Chair: Keiya Shirahama**	
09:00	P3.1	John Beamish	Elasticity, Plasticity and Defects in Helium Crystals **[Plenary Talk]**
09:40	O3.1	Ariel Haziot	The Giant Plasticity of a Quantum Crystal
10:00	O3.2	John Reppy	Pursuit of the Elusive Supersolid
10:20	O3.3	Emil Polturak	Microscopic Measurement of Flow of hcp Solid ^{4}He
10:40		Coffee Break	
Session 3.2: Quantum Fluids		**Chair: Seiji Higashitani**	
11:10	O3.4	Anton Vorontsov	Flow-Induced Phase Transitions in Superfluid ^{3}He Films
11:30	O3.5	Ambarish Ghosh	High Speed Imaging of Generation and Collapse of Multielectron Bubbles in Liquid Helium
11:50	O3.6	Wanchun Wei	Experiments to Study the Exotic Ions and the Effect of Light on Electron Bubbles in Superfluid Helium
12:10		Lunch	
Session 3.3: Low Dimensional Systems		**Chair: Paul Leiderer**	
13:30	P3.2	Hiroshi Fukuyama	Exotic Quantum Phases of ^{3}He and ^{4}He in Two Dimensions **[Plenary Talk]**
14:10	O3.7	Frank Gasparini	Confined ^{4}He Near T_λ: Scaling, Coupling and Proximity Effects
14:30	O3.8	Adrian Del Maestro	Local Superfluidity at the Nanoscale
14:50	O3.9	Satoshi Murakawa	Superfluid Flow and Dissipation of ^{4}He Confined in a Well-Controlled Nanopore Array
15:10		Coffee Break	
Session 3.4: Quantum Gases		**Chair: Kenichi Kasamatsu**	
15:40	O3.10	Jacques Tempere	Vortex-Antivortex Unbinding in Inhomogeneous Atomic Condensates
16:00	O3.11	Eckhard Krotscheck	Dynamic Structure Function of a Cold Fermi Gas at Unitarity
16:20	O3.12	Takafumi Kita	Excitations in Bose-Einstein Condensates Revisited
17:00	PS3	**Poster Session 3:**	Quantum Solids, Quantum Gases

Monday August 5th

Session 5.1: Topological Quantum Phenomena			**Chair: William Halperin**
09:00	P5.1	Yoshiteru Maeno	Topological Superconductors and Superfluids [**Plenary Talk**]
09:40	O5.1	Satoshi Sasaki	Experimental Efforts to Realize Time-Reversal Invariant Topological Superconductors
10:00	O5.2	Takeshi Mizushima	Topological Superfluidity of ^{3}He
10:20	O5.3	Osamu Ishikawa	New Boundary Phenomena of Liquid ^{3}He in Aerogel Contacting with Superfluid ^{3}He-B
10:40		Coffee Break	
Session 5.2: Quantum Turbulence			**Chair: Ladik Skrbek**
11:10	O5.4	Victor Tsepelin	The Turbulent Drag in Superfluids
11:30	O5.5	Risto Hánninen	Dissipation Enhancement from a Single Reconnection Event in Superfluid Helium
11:50	O5.6	Carlo Barenghi	Finite-Temperature Vortex Decay, Core Brightness and Turbulence in Atomic Bose-Einstein Condensates
12:10		Lunch	
Session 5.3: Exciton-Polariton			**Chair: Makoto Tsubota**
13:30	P5.2	Pavlos Savvidis	Exciton-Polariton Condensates in Semiconductor Microcavities [**Plenary Talk**]
14:10	O5.7	Mike Fraser	Modified Excitation Spectrum and Superfluidity in Open-Dissipative Polariton Condensates
14:30	O5.8	Kosuke Yoshioka	Towards a Stable Bose-Einstein Condensate of Excitons in a Bulk Semiconductor
14:50		Coffee Break	
Session 5.4: Quantum Fluids & Solids			**Chair: Akira Yamaguchi**
15:50	O5.9	Izumi Iwasa	Ultrasound Measurement in Solid Helium in a Torsional Oscillator
16:10	O5.10	Xavier Rojas	First-sound Measurements of Liquid ^{4}He near T_λ in Microfluidic Devices
16:30	O5.11	Aaron Koga	Discontinuous Growth of Solid ^{4}He From the Superfluid Phase on Graphene Nanoplatelets
17:00	PS5	**Poster Session 5:**	Low-Dimensional Systems

Tuesday August 6th

Session 6.1: Low Dimensional Systems			**Chair: Nobuo Wada**
09:00	P6.1	John Saunders	Topological Superfluids Confined in Nanoscale Slab Geometries **[Plenary Talk]**
09:40	O6.1	Ryuji Nomura	Self-Organized Criticality in Quantum Crystallization of ^{4}He in Aerogel
10:00	O6.2	David Rees	Phase Diagram of a Classical Quasi-One-Dimensional Electron System
10:20	O6.3	Sachiko Nakamura	Gas-Liquid Transition and Elementary Excitations in Monolayers of Helium-4
10:40		Coffee Break	
Session 6.2: Quantum Fluids and Particle Physics			**Chair: Muneto Nitta**
11:10	P6.2	Grisha Volovik	Higgs Bosons in Particle Physics and in Condensed Matter **[Plenary Talk]**
11:50		**Closing Ceremony**	

Posters

Poster should be mounted at the start of the day of your poster presentation and removed at the end of the poster session. Poster boards are identified by a number. Each poster has an identifier of the form **PSx.y** where **x** gives to the session number (the date of August) and **y** identifies the poster board. For example, PS2.10 is allocated to the Poster Session 2 held on Friday August 2nd on poster board 10.
The lists below give the presenting author only, see the complete abstracts for further details.

Thursday August 1st

Li Jia	PS1.1	The effect of aerogel anisotropy on superfluid ^{3}He-A
Surovtsev E.	PS1.2	NMR properties of the distorted axi-planar superfluid phase of ^{3}He in the "nematically ordered" aerogel
Zhelev N.	PS1.3	Dissipation signatures of the normal and superfluid phases in torsion pendulum experiments with ^{3}He in aerogel
Senin A.	PS1.4	Studies of superfluid low temperature phase of ^{3}He in "ordered" aerogel
Dmitriev V. V.	PS1.5	Widths of NMR lines of superfluid ^{3}He confined by "ordered" aerogel
Morioka Yu	PS1.6	Observation of ^{3}He-B Texture Transition in Aerogel
Kondo K.	PS1.7	Investigation of the Odd-Frequency Pairing in Liquid ^{3}He at Aerogel Interface
Manninen M. S.	PS1.8	Excitation and Detection of Surface Gravity Waves on Normal and Superfluid ^{3}He
Wu Hao	PS1.9	Signatures of Majorana Surface States of Superfluid ^{3}He-B
Zavjalov V.	PS1.10	Spontaneous formation of magnon Q-ball in superfluid ^{3}He-B
Kimura Y.	PS1.11	Detection of Half Quantum Vortex between Parallel Plates in Superfluid ^{3}He-A
Kunimatsu T.	PS1.12	NMR on Texture of Rotating Superfluid ^{3}He-A phase in a narrow cylinder
Benningshof O.	PS1.13	Spin waves in the B-phase of superfluid ^{3}He in (confined) cylindrical geometry
Collett C.	PS1.14	A Variable Path Length Cell for Transverse Acoustic Studies of Superfluid ^{3}He
Tsutsumi Y.	PS1.15	Mass Current at a Domain Wall in Superfluid ^{3}He A-Phase
Nagai K.	PS1.16	Quasi-classical Theory of the A-phase of Superfluid ^{3}He-A in a Cylinder
Takeuchi H.	PS1.17	Anomalous superflow along an interface between aerogel and superfluid ^{3}He
Kawakami T.	PS1.18	Quasiparticle bound states of vortices in superfluid ^{3}He-B phase
Lichtenegger Th.	PS1.19	Density and spin–density fluctuations in liquid ^{3}He
Higashitani S.	PS1.20	Effect of Odd-Frequency Cooper Pairing on Pauli Spin Susceptibility in a Superfluid Proximity System
Kamada N.	PS1.21	Packed powder as superleak for spin pump experiments in superfluid ^{3}He-A1
Gritsenko G.	PS1.22	Observation of heterogeneous nucleation in dilute ^{3}He-^{4}He mixtures
Batulin R.	PS1.23	Laser spectroscopy of Ba^+ ions in liquid He: Towards the detection of Majorana fermion surface state in superfluid ^{3}He-B
Sheshin G.	PS1.24	The influence of the acoustic radiation on the onset of the turbulent flow in He II

Karasevskii A.	PS1.26	The excitations of atoms in helium system
Tayurskii D.	PS1.27	Simulation of liquid helium-4 in aerogel by means of the density functional theory
Panochko G.	PS1.28	Theory of liquid Helium-4 in a deformed Heisenberg space
Krotscheck E.	PS1.29	Spinodal decomposition of two-dimensional ^{3}He at low densities
Abdurakhimov L.	PS1.30	Redistribution of 2D Electrons on Liquid Helium under Pulse-Modulated MW Irradiation
Abdurakhimov L.	PS1.31	The Role of Resonance Conditions at the Edge of 2D Electron Pool in MW-Induced Zero-Resistance States Formation in 2DES on Liquid Helium
Abdurakhimov L.	PS1.32	Excitation of Surface Waves by Second Sound Waves in Superfluid Helium-4
Abdurakhimov L.	PS1.33	Magneto-Oscillations Induced by Frequency-Modulated MW-Irradiation in 2DES on Liquid Helium Surface
Nyeki Jan	PS1.34	Superfluid Response and Quantum Criticality of Two Dimensional ^{4}He on a Triangular Lattice
Badrutdinov A.	PS1.35	Cyclotron-resonance-induced dynamics of the electrons-on-helium system
Konstantinov D.	PS1.36	Effects of strong internal forces on microwave-induced magneto-oscillations in surface electrons on liquid helium
De Lorenzo L.	PS1.37	Superfluid Helium-4 as an Ultra-low Loss Optomechanical Element: Coupling the motion of superfluid and superconducting condensates
Schmoranzer D.	PS1.38	Quadratic damping of mechanical oscillators and its effect on their resonant response
Fortes M.	PS1.39	Superfluidity of a spin-imbalanced Fermi gas in a three-dimensional optical lattice
Sakhi S.	PS1.40	Quantum critical properties in the topological Ginzburg-Landau theory of self-dual Josephson junction arrays
Shevchenko S. I.	PS1.41	On electrical fields in dielectrics caused by temperature gradient
Konno R.	PS1.42	The Pressure Coefficients of the Superconducting Order Parameters at the Ground State of Ferromagnetic Superconductors
Vdovychenko G.	PS1.43	Self-organizing disorder and low-temperature thermal conductivity of molecular crystals
Kanazawa I.	PS1.44	Photo-induced Quantum Phase Transition and Magnetic Solitons in the Perovskite GdSrMnO

Friday August 2nd

Zmeev D.	PS2.1	Quantum Turbulence Produced by Uniformly Moving Grid in ^{4}He in the T=0 Limit
Saluto L.	PS2.2	Superfluid counterflow turbulence in short channels
Saluto L.	PS2.3	Vortex diffusion in axial quantum turbulence
Sarsby M.	PS2.4	Quantum Turbulence Decay Observations in a Black Body Radiator
Oda S.	PS2.5	Observations of vortex emissions from superfluid ^{4}He turbulence at high temperatures
Walmsley P.	PS2.6	Emission of small vortex loops due to reconnections of quantized vortices in superfluid ^{4}He at low temperatures
Pakpour F.	PS2.7	Interaction of Excimer He$_2^*$ Molecules with Vortex Lines in Superfluid ^{4}He at $T < 0.2$ K
Yamasaki N.	PS2.8	Dynamics of a particle and a quantized vortex at zero temperature : self-consistent calculation
Nakatsuji Ai	PS2.9	Dynamics of the Cluster of Vortex Points in Two-Dimensional Superfluid ^{4}He
Sergeev Yu. A.	PS2.10	Andreev scattering in turbulent ^{3}He-B: a three-dimensional numerical analysis
Lawson Ch.	PS2.11	Anomalous damping of a low frequency vibrating wire in superfluid ^{3}He-B due to vortex shielding
Lawson Ch.	PS2.12	Switching Behaviour of a Quartz Tuning Fork in Superfluid ^{4}He
Makinen J.	PS2.13	Energy dissipation and librating motion of superfluid ^{3}He-B in the $T \to 0$ limit
Guise E.	PS2.14	Design and Characterisation of a Detector for Quasiparticle and Quantum Turbulence Imaging Studies in Superfluid ^{3}He
Jackson M.	PS2.15	Damping of Mechanical Oscillators During the Turbulent Transition in ^{4}He
Woods A.	PS2.16	Frequency Dependence of the Transition to Quantum Turbulence in Superfluid ^{4}He
Sciacca M.	PS2.17	Numerical and statistical analysis of pure superflow
Sciacca M.	PS2.18	Numerical experiments on a two dimensional counterflow channel in helium II by means of a one-fluid model
Galantucci L.	PS2.19	Counterflow channel: statistical studies on the normal component
Shiozaki R. F.	PS2.20	Quantum Turbulence in a harmonically trapped Bose-Einstein Condensate: from Vortices to Granulation
Karl M.	PS2.21	Nonthermal Fixed Points and Superfluid Turbulence in an Ultracold Bose Gas
Chung C.-K.	PS2.22	Zero-field vortex-induced Hall effect and polar Kerr effect in chiral p-wave superconductors near Kosterlitz-Thouless transition
Tinh Bui Duc	PS2.23	Ac fluctuation conductivity in strongly fluctuating layered superconductors under magnetic field
Kamran M.	PS2.24	IV characteristics of array of antidots on superconducting Nb film
Kamran M.	PS2.25	Magneto-resistance of a complex system i.e., Kagome array of antidots (holes)
Arahata E.	PS2.26	DC conductivity in a s-wave superconducting single vortex system
Kurosawa N.	PS2.27	Impurity effects in a vortex core in a chiral p-wave superconductor within the t-matrix approximation
Babuin S.	PS2.28	Decay of Quantum Turbulence Generated by Forced Flows of Superfluid ^{4}He
Duda D.	PS2.29	Dynamics of Solid Deuterium Particles in Quantum Turbulence Generated in Thermal Counterflow
Akiyama K.	PS2.30	Parallel Plates for Surface Magnetization Measurements of Superfluid ^{3}He

Collin E.	PS2.31	Modal Decomposition in Goalpost Micro/nano Electro-mechanical Devices
Bosch W. A.	PS2.32	SRD1000 and CMN1000 sensors for precision thermometry below 8 K
Abdelrahman A.	PS2.33	Quantum Information Processing with Magnetically Trapped BECs in Cavity QEDs
Clovecko M.	PS2.34	Vacuum measurements of a novel micro-resonator based on tin whiskers performed at mK temperatures
Arnold F.	PS2.35	Characterisation of a New Graphite Substrate for Measurements of Adsorbed Gases
Takahashi T.	PS2.36	A ^{3}He-^{4}He Dilution Refrigerator for Microgravity Experiments on a Small Jet Plane
Zmeev D.	PS2.37	A Method for Driving an Oscillator at a Quasi-Uniform Velocity
Obara K.	PS2.38	Development of Fiber-Optic Probe Hydrophone for Cryogenic Liquid
Matthews A. J.	PS2.39	A microKelvin cryogen-free platform
Fleischmann Ch.	PS2.40	A Flux Noise Thermometer Optimized for Use at Ultralow Temperatures

Saturday August 3rd

Balibar S.	PS3.1	Stacking fault energy and dislocation splitting in ^{4}He crystals
Haziot A.	PS3.2	Evidence for a critical dislocation speed in helium-4 crystals
Mikhin N.	PS3.3	Vitrification of Liquid Inclusions in hcp ^{3}He-^{4}He Crystal: the Role of an Intermediate bcc Phase
Mikhin N.	PS3.4	The plastic flow of solid ^{4}He through a porous membrane
Tsuiki T.	PS3.5	Nature of the Quantum Oscillation of Solid ^{4}He under DC Rotation
Kubota M.	PS3.6	Quantum Vortex Physics in hcp solid ^{4}He
Zmeev D.	PS3.7	Shear Modulus and Thermal Conductivity of Polycrystalline hcp ^{4}He at Low Temperatures
Ahlstrom S.	PS3.8	Response of a Mechanical Oscillator in Solid ^{4}He
Ahlstrom S.	PS3.9	Plastic Properties of Solid ^{4}He Probed by a Moving Wire: Viscoelastic and Stochastic Behavior Under High Stress
Krainyukova N.	PS3.10	Supersolidity Mimics Superfluidity in Other Scale
Krainyukova N.	PS3.11	Rotational, Vibrational and Glassy States in Solid Helium with Impurities
Fefferman A.	PS3.12	The distribution of dislocation lengths in ^{4}He crystals
Moroshkin P.	PS3.13	Disorder and melting in doped solid helium studied by dopant laser spectroscopy
Sullivan N.	PS3.14	Lattice Relaxation in Solid ^{4}He — Effect on Dynamics of ^{3}He Impurities
Kamada M.	PS3.15	Specific Heat Measurement of the Gapless Spin Liquid State in 2D ^{3}He
Yoshida T.	PS3.16	^{4}He crystals on an oscillating plate
Kubota Y.	PS3.17	Search for Supersolidity in Monolayer ^{4}He on Graphite
Nomura R.	PS3.18	Falling and collision of ^{4}He crystals in superfluid
Takahashi T.	PS3.19	Gravity-Free ^{4}He Crystals in Superfluid at 150 mK
Aoki Y.	PS3.20	Frequency change of torsional oscillator induced by solid ^{4}He in torsion rod
Isozaki R.	PS3.21	Power law behavior of quantum crystallization of ^{4}He in aerogel
Matsuda H.	PS3.22	Fluctuating surfaces of growing ^{4}He crystals in aerogel
Chishko K.	PS3.23	Macroscopic Density Fluctuations and Metastable States of ^{3}He-^{4}He Solid Solutions in Pre-separation Region
Yamashita K.	PS3.24	Gas-Solid Phase Transition in Hardcore-like Systems
Dubovskii L.	PS3.25	On the Lifetime of Metastable Metallic Hydrogen
Ahokas J.	PS3.26	Magnetic resonance study of atomic hydrogen and deuterium in solid H_2 and D_2 matrices below 1 K
Park S.	PS3.27	Helium Buckyballs on the H_2-preplated C_{20} Surface
Jarvinen J.	PS3.28	Dynamic nuclear polarization and relaxation in Si:P at very low temperatures
Babaei-Brojeny A.	PS3.29	Enhancement of the magnetic flux in a superconducting system of the multiple thin strips
Ramirez C.	PS3.30	Bose-Einstein condensation of collective Cooper pairs

Shin J. H.	PS3.31	Simultaneous Measurements of Torsional Oscillator and Shear Modulus of Solid Helium-4 with 1ppb ^{3}He impurity
Choi J.	PS3.32	Observation of NCRI in Solid Helium-4 by using Rigid Double Pendulum Torsional Oscillator
Souris F.	PS3.33	Stability limit of a metastable state of hcp solid helium-4
Konstantinov D.	PS3.34	Magnon BEC in $RbMnF_3$ and $MnCO_3$ at a temperature about 1 K
Tsutsui K.	PS3.35	Ground-State Energy and Condensate Density of a Dilute Bose Gas Revisited
Kunimi M.	PS3.36	Precursor phenomena of nucleations of quantized vortices in the presence of a uniformly moving obstacle in Bose-Einstein condensates
Takahashi D.	PS3.37	Self-consistent multi-soliton solutions in Bogoliubov-de Gennes systems
Danshita I.	PS3.38	Quantum phase slips of trapped superfluid Bose gases in one dimension
Fujimoto K.	PS3.39	Spin turbulence in spin-1 spinor Bose-Einstein condensate with antiferromagnetic interaction
Aoki Y.	PS3.40	Spin-glass-like behavior of spin turbulence in spinor Bose-Einstein condensates
Takeuchi H.	PS3.41	Diffusion of Vortices to ‘ Extra-Dimension ’ in Tachyon Condensation via Domain Wall Annihilation in Segregated Bose-Einstein Condensates
Ishino S.	PS3.42	Instability of Counter-rotating Vortices in miscible two-component Bose-Einstein condensates
Thompson K.	PS3.43	Characterization of an apparatus and theoretical predictions for a two species BEC turbulence experiment
Telles G.	PS3.44	Observation of anomalous momentum distribution in a turbulent Bose-Einstein Condensate
Kasamatsu K.	PS3.45	Implementation of Lattice Gauge-Higgs Model in Quantum Simulators of Cold Atoms
Li Ben	PS3.46	Spin-Orbit Coupled Bose-Einstein Condensates in Optical Lattices
Shinozaki M.	PS3.47	Elementary excitations of antiferromagnetic spin-1 bosons in an optical lattice
Yamamoto D.	PS3.48	First-Order Phase Transition and Anomalous Hysteresis of Binary Bose Mixtures in an Optical Lattice
Sato C.	PS3.49	Fermi superfluid on the Lieb lattice
Tempere J.	PS3.50	Time dependent Ginzburg-Landau formalism for two-bandgap Fermi systems
Endo Yuki	PS3.51	Superfluid theory of a gas of polarized dipolar Fermi molecules
Tajima H.	PS3.52	Spin Susceptibility and Strong Coupling Effects in an Ultracold Fermi Gas
Krotscheck E.	PS3.53	Non-Fermi Liquid Nature of the Two-dimensional Dipolar Fermi Gas
Pedrozo E.	PS3.54	Two-componet BEC for Studying Quantum Turbulence
Marmorini G.	PS3.55	Exact Self-Consistent Condensates in (Imbalanced) quasi-1D Superfluid Fermi Gases
Lutsyshyn Y.	PS3.56	Variational description of the exchange-driven liquid-to-solid quantum phase transition in ^{4}He
Hanai R.	PS3.57	Self-consistent T-matrix approach to an interacting ultracold Fermi gas with mass imbalance
Kobayashi M.	PS3.58	Vortex polygons and their stabilities in Bose-Einstein condensates and field theory

Monday August 5th

Salas P.	PS5.1	Fermi and Bose gases within Multitubes
Solis M. A.	PS5.2	BEC and dimensional crossover in a boson gas within multi-slabs
Ogata Yu	PS5.3	Possible Phase Diagram of Imperfect Bose Liquid in Nanoporous Glass
Kaminaka T.	PS5.4	Exact Analysis of a One-Dimensional Weakly Repulsive Bose-Fermi Mixture
Chishko K.	PS5.5	^{3}He Monolayers on Graphite in Ferromagnetic Regime: Cluster Size Effect
Matsumoto K.	PS5.6	Anisotropy of the Adiabatic Relaxation Time of Adsorbed ^{3}He Monolayer
Matsushita T.	PS5.7	NMR study on motional state of helium film adsorbed in nanochannels of FSM silicate
Wada N.	PS5.8	Three-Dimensional Boltzmann Gas and Possible Singlet Bound State of ^{3}He Film Formed in Nanopore of HMM-2
Hieda M.	PS5.9	Submonolayer Superfluidity of ^{4}He Films on Planar Gold
Kulchytskyy B.	PS5.10	Helium-4 crossover from a 3d superfluid to a 1d Luttinger liquid in a nanopore
Endoh T.	PS5.11	Frequency-independent 1D superfluid response in ^{4}He film adsorbed in nanochannels
Suzuki M.	PS5.12	Highly mobile metastable state of ^{4}He thin layers above the KT transition temperature
Taniguchi J.	PS5.13	Competition between superfluid overlayer and mobile solid layer of ^{3}He-^{4}He mixture films on porous gold
Demura K.	PS5.14	^{3}He impurity effect on the superfluidity for liquid ^{4}He confined in 1D nano-porous medium FSM16
Morishita M.	PS5.15	Reentrant Solidification of First Layer of ^{4}He Film on Graphite
Arnold F.	PS5.16	SQUID-NMR studies of ^{3}He Films on Graphite in the Microkelvin Temperature Range
Yayama H.	PS5.17	Mobility of 2D Electrons on pure ^{4}He and ^{3}He–^{4}He dilute solution
Zadorozhko O.	PS5.18	Fabrication of graphite substrates to study two dimensional helium films
Beysengulov N.	PS5.19	Nonlinear Transport of the Wigner Crystal in a Confinement Geometry
Rovenchak A.	PS5.20	Complex-valued fractional statistics for D-dimensional harmonic oscillators
Sanchez V.	PS5.21	Improving the ballistic ac conductivity through quantum resonance in nanowires
Smorodin A. V.	PS5.22	Surface electron transport over structured silicon substrate, limited by ripplon and gas scattering
Degtiarov I.	PS5.23	Dispersion of Collective Modes in Electron Quantum Wire Over Liquid Helium in a Magnetic Field
Sharma P.	PS5.24	Transport in Fermi Liquids Confined by Rough Walls
Moriyama S.	PS5.25	Superconducting Fluctuations and Phase Slips in Niobium-Nitride Nanowires on Suspended Carbon Nanotubes
Nakamura S.	PS5.26	A New Heat-Capacity Anomaly at the Melting Transition in the Second Layer of ^{3}He on Graphite
Nemchenko K. E.	PS5.27	Quantitative Ratio between Heat Flows due to Sound and Diffusion in Superfluid Helium

Abstracts

Invited Oral Presentations: Thursday August 1st

P1.1 Experimental signatures of vortex core structures in superfluid ^{3}He

V.B. Eltsov

O.V. Lounasmaa Laboratory, Aalto University, P.O. Box 15100, FI-00076 AALTO, Finland

The superfluid phases of ^{3}He were the first experimentally accessible macroscopic quantum systems where the multi-component order parameter supports a variety of quantized vortices with non-singular, i.e. superfluid, cores. Such vortices can possess hard cores with the radius of about the coherence length, filled with a superfluid phase, different from that in the bulk. An other alternative is a much larger skyrmion-like soft core, where only the orientation of the order parameter changes. These unconventional structures lead for example to the broken axial symmetry and spontaneous magnetization of vortex cores and to the existence of double- and half-quantum vortices. The Caroli-de Gennes-Matricon picture of the vortex-core-bound fermions is modified with the inclusion of zero-energy states or fermionic flat bands in the cores, the lifting of the spin degeneracy and other consequences of broken symmetries. A short overview of these features will be presented, in view of the growing interest in unconventional vortex structures in multi-component Bose-Einstein condensates of cold atoms, superconductors with p- and d-wave pairing and artificially engineered topological superconductors.

Many of these features of the vortices in superfluid ^{3}He were experimentally established by probing the order-parameter structure in a rotating sample with the nuclear magnetic resonance techniques and by measuring vortex dynamics. Recent work at temperatures below $0.2\,T_\mathrm{c}$ provides new information on the interaction of the soft- and hard-core vortices at the interface between A and B phases of ^{3}He and on the fermions bound to the hard cores of the B-phase vortices. The core-bound fermions are detected using coherent spin precession of the BEC of magnon quasiparticles, while the rotational motion of the non-axisymmetric vortex cores provides the coupling mechanism between the two subsystems.

O1.1 Chiral textures in slabs of superfluid ^{3}He-A

P. M. Walmsley and A. I. Golov

School of Physics and Astronomy, The University of Manchester, Manchester, M13 9PL, United Kingdom

We have used torsional oscillators, containing disk-shaped slabs of superfluid ^{3}He-A, to probe the chiral orbital textures created by cooling into the superfluid state while continuously rotating. Comparing the observed flow-driven textural transitions with numerical simulations of possible textures shows that an oriented monodomain texture with $\hat{\mathbf{l}}$ *antiparallel* to the angular velocity $\mathbf{\Omega_0}$ is left behind after stopping rotation. The bias toward a particular chirality, while in the vortex state, is due to the inequivalence of energies of vortices of opposite circulation. When spun-up from rest, the critical velocity for vortex nucleation depends on the sense of rotation relative to that of $\hat{\mathbf{l}}$. A different type of vorticity, apparently linked to the slab's rim by a domain wall, appears when the angular velocity, $\mathbf{\Omega}$, is parallel to $\hat{\mathbf{l}}$.

[1] P. M. Walmsley and A. I. Golov, Phys. Rev. Lett. **109**, 215301 (2012).

[2] G. E. Volovik and M. Krusius, Physics **5**, 130 (2012).

O1.2 Direct Detection of Chirality in Superfluid ^{3}He-A

H. Ikegami[a, b], Y. Tsutsumi[c], and K. Kono[a, b]

[a]Low Temperature Physics Laboratory, RIKEN, Japan

[b]The RIKEN Center for Emergent Matter Science, RIKEN, Japan

[c]Condensed Matter Theory Laboratory, RIKEN, Japan

We report direct detection of chirality in superfluid ^{3}He-A by a novel, intrinsic Magnus force[1,2] experienced by a moving ion. When an ion moves in a plane perpendicular to the l vector, it may experience the intrinsic Magnus force in the direction perpendicular to both its velocity and l, as a result of the skew scattering of quasiparticles by the ion[1,2]. We detected the intrinsic Magnus force by transport measurements of negative ions, or electron bubbles, trapped below a free surface of superfluid ^{3}He at a depth about 30 nm. At the surface, l aligns normal to the surface uniformly, and the ions moving along the surface is therefore subjected to the intrinsic Magnus force. We observed transverse current associated with the intrinsic Magnus force. The transverse current shows two types of temperature dependences, which are equal in magnitude but opposite in sign. These two correspond to the two chiralities, i.e., l pointing either upward or downward. The observation of the two chiralities at different cooling runs suggests that either chirality is selected at the superfluid transition upon cooling.

1. R. H. Salmelin *et al.*, Phys. Rev. Lett. **63**, 868 (1989).
2. R. H. Salmelin and M. M. Salomaa, Phys. Rev. B **41**, 4142 (1990).

O1.3 Gravity waves on the surface of topological superfluid ^{3}He-B

P. J. Heikkinen, V. B. Eltsov, and V. V. Zavjalov

O. V. Lounasmaa Laboratory, Aalto University, P.O. Box 15100, FI-00076 AALTO, Finland

Waves on the surface of a fluid in a gravitational field are among the most ubiquitous phenomena in nature. We report the first observation of the gravity waves on the surface of superfluid ^{3}He-B at temperatures below $0.2\,T_c$ in the ballistic regime of quasiparticle motion [1]. At higher temperatures the gravity waves are damped by the large viscosity of the normal component, and only the third sound waves in a thin film have been observed. We excite the waves by vibrating vertical cylindrical container filled partially with ^{3}He-B. The oscillating free surface is coupled to the magnon Bose-Einstein condensate in a magneto-textural trap [2]. In the magnon BEC the magnetization of ^{3}He precesses with coherent phase and common frequency, which is determined by the trapping potential. The oscillating surface modifies the trap shape and modulates the frequency. By measuring the precession frequency of magnetization we have identified the two lowest surface wave modes of our system. Our measurements show that the damping of the waves decreases with temperature linearly with the density of the normal component and extrapolates to a finite value at zero temperature. We have also observed enhancement of relaxation rate of the trapped magnon condensate when the surface waves modulate the trap, whereas the similar modulation of the trap with the magnetic field does not affect the relaxation. We discuss the possibility that both the finite damping at $T = 0$ and the enhanced magnon relaxation could be related to the surface-bound Majorana states expected to exist at the free surface of topological superfluid ^{3}He-B.

1. V. B. Eltsov *et al.*, arXiv:1302.0764.
2. S. Autti *et al.*, PRL **108**, 145303 (2012).

P1.2 **Liquid ^{3}He in Random Media**

J. A. Sauls

Department of Physics and Astronomy, Northwestern University, Evanston, USA

Liquid ^{3}He is the purest form of matter in the universe. Any impurity, even the isotope ^{4}He is expelled by the large zero-point pressure of the fluid. The discovery that liquid ^{3}He could be infused into ultra-low density glass - silica aerogel - and exhibited superfluidity even under confinement in this complex material was profound. Silica aerogel is a network of strands and clusters of SiO_2 that is mostly empty space. This *gossamer* structure is a *random fractal* - a structure with no long-range order, but power-law scaling of the density correlation function over several decades of spatial scales. I illustrate these properties with simulations of the growth of silica aerogels and describe the structure and some of the ideas proposed that make these complex structures of interest for investigating the effects of disorder, spatial confinement and correlations on the ordered phases of a superfluid ^{3}He. I discuss recent advances based on the fabrication of *anisotropic* of silica aerogels with exceptional homogeneity. Liquid ^{3}He infused into anisotropic aerogels provides new insights into the nature of unconventional pairing in disordered anisotropic media. I report theoretical predictions and analysis for the phases of superfluid ^{3}He infused into homogeneous *uniaxial* "stretched" and "compressed" aerogels. I present a theory that incorporates the effects of both local and global anisotropy on the phase diagram and NMR signatures of superfluid ^{3}He in anisotropic aeorgels. In this model random anisotropy originates from mesoscopic structures in silica aerogels. This random field model is coarse-grained on the atomic scale, and formulated in terms of local anisotropy in the scattering of quasiparticles in an aerogel with orientational correlations. Long-range orientational order of anisotropic scattering centers is related to the phases observed in globally anisotropic aerogels. This research is supported by NSF Grant: DMR-1106315.

O1.4 **Superfluid Phases of ^{3}He in "Ordered" Aerogel**

V. V. Dmitriev, E. E. Efimenko, D. A. Krasnikhin, A. A. Senin, and A. N. Yudin

Kapitza Institute, Moscow, Russian Academy of Sciences, Moscow, Russia

We report the results of systematic studies of superfluid states of ^{3}He in "ordered" aerogel. This aerogel is strongly anisotropic because it consists of Al_2O_3 strands which are nearly parallel to each other. Two kinds of superfluid phases were observed in this system earlier[1]: the low temperature phase (LTP) and two high temperature phases (Equal Spin Pairing phases - ESP1 and ESP2). Also the ESP1 phase was previously proved to have ABM order parameter with strong polar distortion, which value depends on pressure and temperature. At low pressures and near the superfluid transition the ESP1 phase presumably corresponds to the pure polar phase. Recent analysis of the NMR linewidths has allowed us to find the possible region of the existence of the pure polar phase. Additional measurements also show that the LTP corresponds to BW phase with strong polar distortion. As for the ESP2 phase (which is observed only at high pressures) we assume that it has the same order parameter as the ESP1 phase (i.e. ABM with polar distortion), but has a different spatial distribution of orbital part of the order parameter.

1. R.Sh.Askhadullin, V.V.Dmitriev, D.A.Krasnikhin et al., JETP Lett. **95**, 326 (2012).

O1.5 ^{3}He in Aerogel: Engineering Superfluid States with Disorder

J. Pollanen, J.I.A. Li, C.A. Collett, W.J. Gannon, A.M. Zimmerman, W.P. Halperin, and J.A. Sauls

Department of Physics and Astronomy, Northwestern University, Evanston, IL 60208, USA

Impurities strongly suppress superconducting states with non-zero orbital angular momentum, a fact that is important as a signature of their unconventional nature. Superfluid ^{3}He confined to high porosity silica aerogel has become a paradigm system for understanding impurity effects in unconventional superconductors. We have developed a new class of highly homogeneous aerogel materials to explore the role of engineered disorder on phase stability and orientation of the superfluid order parameter. Using pulsed nuclear magnetic resonance (NMR) we are able to definitively identify the superfluid states in aerogel and have discovered that anisotropic disorder, produced by growth-induced radial compression, stabilizes a chiral superfluid state that otherwise would not exist. Additionally, from the dependence of the NMR frequency shifts on temperature and tip angle, we have determined the orientation of the orbital angular momentum in this novel state.

O1.6 Possible Phase Diagram of Superfluid ^{3}He in Highly Anisotropic Aerogel

R. Ikeda and R. Oishi

Department of Physics, Kyoto University, Japan

Recent NMR measurements on superfluid ^{3}He in highly anisotropic aerogel have given a convincing evidence that the polar pairing state is the equal-spin pairing (ESP) phase at lower pressures and continuously transforms to the deformed B-phase at lower temperature with no intermediate deformed A-phase.[1] In the present work, we extend our previous calculation[2] to a much more anisotropic case to justify the direct polar to (deformed) B transition. On the other hand, we argue that the polar phase is not lost even at higher pressures, and that an extremely deformed A to polar transition should be seen in the ESP phase with increasing pressure. The half-quantum vortex which, under rotation, should be stable in the polar phase will also be discussed.

1. R. Sh. Ashkhadulin *et al.*, Phase diagram of superfluid ^{3}He in nematically ordered aerogel, Pis'ma v ZhETF (JETP Lett.) **95**, 355 (2012).
2. K. Aoyama and R. Ikeda, Pairing states of superfluid ^{3}He uniaxially anisotropic aerogel, Phys. Rev. B **73**, 060504(R) (2006).

O1.7 Direct Observation of a Majorana Quasiparticle Heat Capacity in ^{3}He

Yu.M. Bunkov

Institute Neel, CNRS, Grenoble, France

The Majorana fermion, which acts as its own antiparticle, was predicted by Majorana in 1937. No fundamental particles are known to be Majorana fermions, although there are speculations that the neutrino may be one. There is also theoretical speculation that Majorana fermions may comprise a large fraction of cosmic Dark Matter. While no stable particle with Majorana properties has yet been observed, Majorana *quasi*particles may exist at the boundaries of topological insulators. Here we report the preliminary results of direct observation of Majorana quasiparticles by deviation of superfluid ^{3}He heat capacity. The superfluid ^{3}He heat capacity falls exponentially with temperature. The Majorana heat capacity follows a power law. By reanalyze the data, published in the article [1] we have found a 10% deviation from exponential law heat capacity at the temperature of 135 μK in a good agreement with the theory [2]. No any fitting parameters was involved in the analyze. The experiments are in progress.

1. J. Elbs, Yu. M. Bunkov, E. Collin, H. Godfrin, O. Suvorova J. of Low Temp. Phys.. 150, 536, (2008)
2. G. E. Volovik, JETP Lett. **90** 398 and 587 (2009).

O1.8 Magnon BEC in antiferromagnets with Suhl-Nakamura interaction

M.S. Tagirov[a], E.M. Alakshin[a], Yu.M. Bunkov[b], R.R. Gazizulin[a], S.A. Zhurkov[c], L.I. Isaenko[c], A.V. Klochkov[a], A.M. Sabitova[a], T.R. Safin[a], and K.R. Safiullin[a]

[a]Institute of Physics, Kazan Federal University, Kazan, Russian Federation
[b]Institute Neel, CNRS, Grenoble, France
[c]V.S. Sobolev Institute of geology and mineralogy, Siberian Branch of Russian Academy of Sciences, Novosibirsk, Russian Federation

The Bose-Einstein condensation (BEC) of magnons and Spin Superfluidity were discovered in 1984 in superfluid ^{3}He-B [1]. It manifests itself by coherent precession of magnetization, even in presence of the inhomogeneous static magnetic field. For the last 25 years 5 different magnon BEC states in superfluid ^{3}He have been found [2]. The possibility of Spin Superfluidity in antiferromagnets with couped nuclear-electron precession was predicted by Yu.M. Bunkov [3]. It can take place in the antiferromagnets with so-called Suhl-Nakamura interaction. The predictions were successfully confirmed. It was found that the coupled nuclear-electron precession shows all properties of coherent spin precession and magnon BEC [4]. This study was partly supported by the Siberian Branch of the Russian Academy of Sciences (Grant N28).

1. Borovik-Romanov A.S., Bunkov Yu.M., Dmitriev, V.V. Mukharskiy Yu.M. JETP Letters 40, 1033 (1984); Fomin I.A. JETP Lett. 40, 1037 (1984).
2. Bunkov Yu.M., Volovik G.E. J. of Phys.: Cond. Matt. 22, 164210 (2010).
3. Bunkov Yu.M. Physics-Uspekhi 53, 848 (2010).
4. Bunkov, Yu.M., Alakshin, E.M. Gazizulin, R.R., et al. Phys. Rev. Lett. 108, 177002 (2012).

O1.9 Non-Fermi liquid behaviour in the heavy-fermion Kondo lattice $Ce_2Rh_3Al_9$

M. Falkowski and A. M. Strydom

Physics Department, University of Johannesburg, PO Box 524, Auckland Park 2006, South Africa

In the heavy-fermion class of strongly correlated electron systems, the Landau Fermi-liquid description of metals has become a rather fragile basis on which to formulate an understanding of their ground state. The proximity to cooperative phenomena such as magnetic order and superconductivity in heavy fermions, and the amenability of Ce- and Yb-based compounds to be tuned into quantum criticality have been found to have severe consequences on the $T \to 0$ thermal scaling of electronic and magnetic properties, and a collection of non-Fermi liquid scaling relations have been established as a consequence of the search for universality. These have proved to be a gateway towards new physics in condensed matter. 4f-electron systems with very low-lying phase magnetic transitions are suitably disposed towards studies of magnetic instabilities. Here we present results of low-temperature studies (magnetic susceptibility, electrical resistivity, and heat capacity) on the heavy-fermion Kondo lattice $Ce_2Rh_3Al_9$ and related compounds. This structure type is assumed also with d-electron elements such as Ir, and for instance with Ga instead of Al. The higher-temperature behaviour in $Ce_2T_3X_9$ compounds was shown[1] to vary in a perplexing manner between strong 4f-electron with conduction electron hybridization that gives way to an intermediate-valent state, and a more subtle hybridization that produces heavy-fermions in a Kondo lattice. Our studies explore the scaling relations and seek to determine whether magnetic ordering might be responsible for the anomalous low-temperature behaviour of $Ce_2Rh_3Al_9$.

1. Buschinger B. *et al.* , (1997) J. Alloys Comp. **260** 44, and Buschinger B. *et al.* , (1998) J. Alloys. Comp. **275-277** 633.

Poster Presentations: Thursday August 1st

PS1.1 The effect of aerogel anisotropy on superfluid ^{3}He-A

J.I.A Li, J. Pollanen, A.M. Zimmerman, C.A. Collett, W.J. Gannon, and W.P. Halperin

Northwestern University, Evanston, IL 60208, USA

It has been predicted that uniaxially compressed silica aerogel orients the angular momentum, $\hat{l}$, in superfluid ^{3}He-A, along the strain axis.[1] Here we report clear experimental evidence that $\hat{l}$ in the A-phase is oriented perpendicular to the strain axis contrary to the theory. We introduced anisotropic impurity into superfluid ^{3}He-A using 20% elastic mechanical compression of two different samples, of highly uniform, isotropic, 98.2% porosity aerogel. Our pulsed nuclear magnetic resonance (NMR) measurements of the spectrum frequency shift, linewidth, and tip angle dependence indicate an axial state on cooling with long range orientational order of the orbital angular momentum, uniformly established throughout the whole sample. The temperature, magnetic field, and tip-angle dependence of the frequency shift demonstrate that the aerogel anisotropy orients the orbital angular momentum perpendicular to the strain axis for both orientations of magnetic field parallel and perpendicular to the strain. Additionally, our comparison of NMR measurements before and after the compression reveal a novel effect of the aerogel anisotropy on superfluid phase stability. While the B-phase is the equilibrium state in the isotropic aerogel in the zero field limit, aerogel anisotropy stabilizes a temperature window of a new superfluid state at low magnetic field. The stability of this new phase decreases with increasing field, disappearing completely at a critical field H_c near 1000 G. At higher fields the A-phase becomes stable indicating a competition between aerogel anisotropy and the magnetic field for stabilization of the A-phase.

1. Volovik, G. E. (2008). "On Larkin-Imry-Ma State of ^{3}He-A in Aerogel". J. Low Temp. Phys., 150, 453.

PS1.2 NMR properties of the distorted axi-planar superfluid phase of ^{3}He in the "nematically ordered" aerogel

E. Surovtsev

P.L. Kapitza Institute for Physical Problems Russian Academy of Sciences, Moscow, Russia

In the recent NMR experiments in the "nematically ordered" aerogel new superfluid state of ^{3}He called ESP2 (Equal Spin Pairing state) was observed. Motivated by this result in our recent paper we reported that in the superfluid ^{3}He subjected to a strong uniaxial anisotropy there appears additional local minimum of Ginzburg-Landau free energy, corresponding to a new phase. In the weak coupling limit the order parameter of this phase coincides with that of the axi-planar phase. In the present report the NMR-properties of this phase are considered in more details. For identification of the new phase the most informative is the NMR shift, measured at a perpendicular orientation of the d.c. magnetic field with respect to the principal anisotropy axis of "nematic" aerogel. Additional deformation of aerogel in a direction perpendicular to this axis lifts degeneracy of the orbital part of the order parameter. For this geometry NMR frequency shift for arbitrary orientation of the order parameter relative to the direction of the magnetic field is found. The answer for Larkin-Imry-Ma state of the new phase is also given.

1. R. Sh. Askhadullin, V.V. Dmitriev, D.A. Krasnikhin et al., Pisma v ZHETF, 95, 355 (2012)

2. I.A. Fomin and E.V. Surovtsev, Pisma v ZHETF, 97, 742 (2013)

PS1.3 Dissipation signatures of the normal and superfluid phases in torsion pendulum experiments with ^{3}He in aerogel

N. Zhelev[a], R.G. Bennett[a], E.N. Smith[a], J. Pollanen[b], W.P. Halperin[c], and J.M Parpia[a]

[a]Cornell University, Ithaca, NY, USA

[b]California Institute of Technology, Pasadena, CA, USA

[c]Northwestern University, Evanston, IL, USA

We present data for energy dissipation (Q^{-1}) over a broad temperature range at various pressures for a torsion pendulum setup used to study ^{3}He confined in 98% open silica aerogel. Values for Q^{-1} above T_c are temperature independent and have a weak pressure dependence. We apply a viscoelastic collision-drag model, which couples the motion of the helium and the aerogel through a frictional relaxation time τ_f. We extend this model by proposing the possibility of an additional source of dissipation inherent to the aerogel, relevant when operating at acoustic frequencies. Accounting for the normal state contribution in the data below T_c, we are left with an extra dissipation intrinsic to the superfluid. Aerogel anisotropy due to 10% axial compression widens the region of metastability for the superfluid Equal Spin Pairing (ESP) state, and we observe ESP phase on cooling and B phase on warming over an extended temperature range. Values for Q^{-1} in the ESP phase are consistently higher than in the B phase and are proportional to ρ_s/ρ until the ESP to B phase transition is attained. While the dissipation for the B phase tends to zero as $T \rightarrow 0$, Q^{-1} exhibits a peak value greater than that at T_c at intermediate temperatures. The small angular velocity and no amplitude dependence of the data precludes quantum turbulence and vorticity. Instead, the pressure dependence of the measured dissipation in both superfluid phases is likely related to the pressure dependence of the gap structure of the "dirty" superfluid. The extra dissipation below T_c is possibly associated with mutual friction between the superfluid phases and the clamped normal fluid.

PS1.4 Studies of superfluid low temperature phase of ^{3}He in "ordered" aerogel

V.V. Dmitriev, E.E. Efimenko, A.A. Senin, A.A. Soldatov, E.V. Surovtsev, and A.N. Yudin

Kapitza Institute, Russian Academy of Sciences, Moscow, Russia

We present the results of NMR experiments with low temperature phase (LTP) of superfluid ^{3}He in "ordered" aerogel. This aerogel is strongly anisotropic: it consists of strands which are nearly parallel to each other.[1,2] Two aerogel samples with different densities (9 mg/cm^3 and 38 mg/cm^3) and diameters of strands (6 nm and 10 nm correspondingly) were used. Experiments were performed in different orientations of magnetic field using both pulse and continuous wave NMR techniques. The results obtained allow us to assume that the order parameter of the LTP has Balian-Werthamer order parameter with strong polar distortion. The comparison of the experimental results with our theoretical model is presented.

1. Askhadullin R.Sh., Martynov P.N., Yudintsev P.A. et al. *J. Phys.: Conf. Ser.* **98** 072012 (2008).
2. Askhadullin R.Sh., Dmitriev V.V., Krasnikhin D.A. et al. *JETP Lett.* **95** 326 (2012).

PS1.5 Widths of NMR lines of superfluid ^{3}He confined by "ordered" aerogel

V. V. Dmitriev, D. A. Krasnikhin, A. A. Senin, and A. N. Yudin

Kapitza Institute, Moscow, Russia, Russian Academy of Science, Moscow, Russia

The"ordered" aerogel consists of Al_2O_3 strands which are nearly parallel to each other. Consequently this aerogel has a strong anisotropy, which distinguishes it from conventional silica aerogels. This anisotropy influences on the order parameter of superfluid phases of ^{3}He in such aerogel. In particular, theory predicts that in this case ABM order parameter should have polar distortion and near the superfluid transition temperature the pure polar phase may emerge[1]. In the experiments described in[2] we proved that the observed high temperature superfluid phase of ^{3}He in "ordered" aerogel (ESP1 phase) has ABM order parameter with strong polar distortion and the lower bound of this distortion was determined. Unfortunately equations of spin dynamics of the distorted ABM phase and the pure polar phase are the same. This fact complicates the exact determination of "distorted ABM - pure polar" phase transition point using only NMR frequency shift data. Here we present results of continuous wave (CW) NMR experiments focused on measurements of NMR linewidths. At low pressures we have observed a certain peculiarity in temperature dependence of CW NMR linewidth at some temperature near the superfluid transition. We assume that this peculiarity appears due to this transition. The obtained phase diagram will be presented.

1. K. Aoyama and R. Ikeda, Phys.Rev. B **73**, 060504 (2006).
2. R.Sh. Askhadullin, V.V. Dmitriev, D.A. Krasnikhin et al., JETP Lett. **95**, 326 (2012).

PS1.6 Observation of ^{3}He-B Texture Transition in Aerogel

Y. Morioka, K. Kondo, Y. Kimura, C. Kato, K. Obara, H. Yano, O. Ishikawa, and T. Hata

Graduate School of Science, Osaka City University, Osaka, Japan

We have studied superfluid ^{3}He in 97.5% porosity aerogel using a saddle shape NMR coil on outside of the columnar glass tube surrounding aerogel. It is found that the aerogel acts as an impurity for liquid ^{3}He and also a small anisotropy of aerogel leads to a noble phase of superfluid ^{3}He. At 22 bar, cooling through T_c^a =1.44 mK, we observed the A-like phase at first. Below 1.26 mK, only the B-like phase signal appeared whose NMR signal has shifted to positive frequency side. Farther cooling below 1.00 mK, NMR signal gradually changed to one of flare-out texture, in which the large peak appeared at the Larmor frequency with the long tail extending to higher frequencies. On warming, the NMR signal became the same shape as the high temperature B-like phase signal. The texture transitions on cooling and warming occurred at nearly the same temperature. Such a texture transition has never observed in bulk ^{3}He. It is a new phenomena which is attributed to aerogel impurity.

PS1.7 Investigation of the Odd-Frequency Pairing in Liquid ^{3}He at Aerogel Interface

K. Kondo, Y. Morioka, Y. Kimura, C. Kato, K. Obara, H. Yano, O. Ishikawa, and T. Hata

Graduate School of Science, Osaka City University, Osaka, Japan

A novel feature of condensate state in liquid ^{3}He is predicted theoretically, which consists of odd-frequency spin triplet s-wave Cooper pairs[1]. Such a spin triplet s-wave state will appear inside aerogel near the surface contacting with superfluid ^{3}He-B. This novel state will show an enhancement of magnetization[2]. In order to detect this proximity effect, we made the interface in columnar glass tube, and set a saddle shape NMR coils on outside of the glass tube at the interface.We performed cw-NMR measurements at 22 bar. At 22 bar, we found that the superfluidity of ^{3}He in aerogel first appeared at the place away from the interface, but near the interface never appeared, even at considerably low temperatures. Moreover, we observed the enhancement of magnetization of liquid ^{3}He inside aerogel at 22 bar. In this poster, we will discuss whether the enhancement is caused by odd-frequency spin triplet s-wave Cooper pairs.

1. S. Higashitani et al., J. Low Temp. Phys., **155**, 83-97 (2009).
2. Yasushi Nagato, Seiji Higashitani, and Katsuhiko Nagai, J. Phys. Soc. Jpn. **78** (2009) 123603.

PS1.8 Excitation and Detection of Surface Gravity Waves on Normal and Superfluid ^{3}He

M. S. Manninen, J.-P. Kaikkonen, V. Peri, J. Rysti, I. Todoshchenko, and J. Tuoriniemi

O. V. Lounasmaa Laboratory, Aalto University, P.O. Box 15100, FI-00076 AALTO, Finland

Surface gravity waves can be used to accurately measure the properties of the fluid surface. Previously surface tension has been determined in normal ^{3}He and superfluid ^{4}He by measuring the resonance frequencies of the waves.[1,2] In superfluid ^{3}He the studies of the surface gravity waves are challenging since the superfluid transition temperature T_c is several orders of magnitude lower than in ^{4}He. Only at temperatures far below T_c the fraction of very viscous normal component of ^{3}He is small enough not to fully damp the waves. Recently the waves have been observed in superfluid ^{3}He with NMR technique.[3]

We have measured surface gravity waves both in normal and superfluid ^{3}He. The waves were excited mechanically by rocking the whole cryostat pneumatically with an air spring at desired frequency. The waves were detected with an interdigital capacitor mounted on a vertical wall of the cuboid experimental volume. Capacitance of the interdigital capacitor was measured with a capacitance bridge and a lock-in amplifier. Variations of the measured capacitance were detected with another lock-in amplifier which was synchronized to the mechanical excitation.

In superfluid ^{3}He we have observed at least eleven resonance frequencies below 12 Hz and at temperatures around 0.2 mK whereas in normal fluid only a few resonances were observable above 50 mK.

1. M. Iino, M. Suzuki, A. J. Ikushima, and Y. Okuda, *J. Low Temp. Phys.* **59**, 291 (1985).
2. M. Iino, M. Suzuki, and A. J. Ikushima, *J. Low Temp. Phys.* **61**, 155 (1985).
3. V. B. Eltsov, P. J. Heikkinen, and V. V. Zavjalov, arXiv:1302.0764

PS1.9 Signatures of Majorana Surface States of Superfluid ^{3}He-B

Hao Wu and J. A. Sauls

Department of Physics and Astronomy, Northwestern University, USA

We report calculations of surface spectrum, spin- and mass current densities originating from the Andreev surface states for confined ^{3}He-B. The surface states are Majorana Fermions with their spins polarized transverse to their direction of propagation along the surface, $\vec{p}_{\|}$. The negative energy states give rise to a ground-state helical spin current confined on the surface. The spectral functions reveal the subtle role of the spin-polarized surface states in relation to the ground-state spin current. By contrast, these states do not contribute to the $T = 0$ mass current. Superfluid flow through a channel of width $D > D_c \approx 10\xi_0$ of confined ^{3}He-B is characterized by the flow field, $\vec{p}_s = \hbar\vec{\nabla}\vartheta$, where $\vartheta(\vec{r})$ is the global phase of the B-phase Cooper pairs. The flow field breaks $SO(2)_{L_z+S_z}$ rotational symmetry, as well time reversal symmetry ($\mathcal{T}$) and particle-hole symmetry ($\mathcal{C}$). However, the Bogoliubov-Nambu Hamiltonian remains invariant under the combined (chiral) symmetry, $\Gamma = \mathcal{C}\mathcal{T}$. As a result the B-phase in the presence of a superflow remains a topological phase with a gapless spectrum of Majorana modes on the surface. Thermal excitation of the Doppler shifted Majorana branches leads to a power law suppression of the superfluid mass current for $0 < T \lesssim 0.5T_c$, providing a direct signature of the Majorana branches of surface excitations in the fully gapped 3D topological superfluid, ^{3}He-B. Quantitative results will be presented for the superfluid fraction (mass current), helical spin current and heat capacity of confined ^{3}He, including the temperature dependences, as well as dependences on confinement, surface scattering and pressure.

Supported by NSF Grant: DMR-1106315.

PS1.10 Spontaneous formation of magnon Q-ball in superfluid ^{3}He-B

V. V. Zavjalov[a], S. Autti[a], V. V. Dmitriev[b], V. B. Eltsov[a], and P. J. Heikkinen[a]

[a]O. V. Lounasmaa Laboratory, Aalto University, P.O. Box 15100, FI-00076 AALTO, Finland

[b]Kapitza Institute for Physical Problems, Kosygin str. 2, Moscow 119334, Russia

Long-living coherent magnetic states can be created by NMR techniques in the ^{3}He-B. These states can be described in terms of Bose-Einstein condensation of magnon quasiparticles. At temperatures below 0.2 T_c magnon condensate can be formed in a pre-defined potential trap created by external magnetic field and inhomogeneous texture of ^{3}He-B order parameter [1]. Unlike Bose-Einstein condensates of cold atoms, magnon BEC in ^{3}He-B is able to modify its trapping potential since the order-parameter texture depends on the magnon density. This property makes the magnon condensate analogous to a so-called Q-ball [2]. A Q-ball in field theories is a soliton of self-localized charge in the scalar field with attractive interaction. In the case of the magnon BEC in ^{3}He-B, the magnon number plays role of the charge and the spin-orbit interaction provides the self-localization. We have observed that the condensate with large enough number of magnons moves from the pre-existing trap to another location forming a new potential trap. This trap exists only while the condensate is localized inside it and thus displays the soliton nature of a "true" Q-ball. We have also observed two coexisting spatially separated magnon condensates in the self-supported and original traps.

1. S. Autti *et al.*, Phys. Rev. Lett. **108**, 145303 (2012).
2. Yu. M. Bunkov, G. E. Volovik, Phys. Rev. Lett. **98**, 265302 (2007).

PS1.11 Detection of Half-Quantum Vortex between Parallel Plates in Superfluid ^{3}He-A

Y. Kimura[a], T. Kunimatsu[a,b], K. Obara[a], H. Yano[a], O. Ishikawa[a], and T. Hata[a]

[a]Graduate School of Science, Osaka City University, Japan

[b]The Institute for Solid State Physics, The University of Tokyo, Japan

In superfluid ^{3}He-A, it was theoretically predicted that the half-quantum vortex (HQV) is stable in the order parameter configuration where the order parameters $\hat{\boldsymbol{d}}$ and $\hat{\boldsymbol{\ell}}$ are perpendicular to each other[1]. However, the existence of the HQV has not been reported so far in experiments with a parallel plate sample cell[2]. We are trying to detect the HQV in ^{3}He-A by using a new technique. In ^{3}He-A, $\hat{\boldsymbol{\ell}}$ is parallel to the surface normal of the sample container, $\hat{\boldsymbol{\nu}}$, due to the anisotropy of ^{3}He-A, and in the presence of a magnetic field, $\boldsymbol{H}$, $\hat{\boldsymbol{d}}$ is perpendicular to $\boldsymbol{H}$ due to the anisotropy of the magnetic energy. If $H > 3$ mT parallel to $\hat{\boldsymbol{\nu}}$ is applied to ^{3}He confined between parallel plates whose gap is as narrow as the dipole coherence length $\sim 10\ \mu$m, we can obtain a $\hat{\boldsymbol{\ell}} \perp \hat{\boldsymbol{d}}$ texture. In the higher magnetic field and under rotation whose axis is parallel to $\hat{\boldsymbol{\nu}}$, the HQV would be generated[3]. In order to detect the HQV, we will use a rotating cryostat at ISSP[2] and perform cw-NMR measurement. Moreover, we will use a new technique of cw-NMR measurement in which the static magnetic field can be tilted to $\hat{\boldsymbol{\nu}}$.

1. M. M. Salomaa and G. E. Volovik, *Phys. Rev. Lett.* **55**, 1184 (1985).
2. M. Yamashita, K. Izumina, A. Matsubara, Y. Sasaki, O. Ishikawa, T. Takagi, M. Kubota, and T. Mizusaki, *Phys. Rev. Lett.* **101**, 025302 (2008).
3. K. Kondo, T. Ohmi, M. Nakahara, T. Kawakami, Y. Tsutsumi, and K. Machida, *J. Phys. Soc. Jpn.* **81**, 104603 (2012).

PS1.12 NMR on Texture of Rotating Superfluid ^{3}He-A phase in a narrow cylinder

T. Kunimatsu[b], H. Nema[c], R. Ishiguro[d], M. Kubota[a], T. Takagi[e], Y. Sasaki[f], and O. Ishikawa[b]

[a]ISSP, The University of Tokyo, Kashiwa, 277-8581, Japan

[b]Graduate School of Science, Osaka City University, Osaka, 558-8585, Japan

[c]Faculty of Science and Engineering, Chuo University, Tokyo, 112-8551, Japan

[d]RIKEN, Hirosawa 2-1, Wako, Saitama 351-0198, Japan

[e]Department of Applied Physics, Fukui University, Fukui, 910-8507, Japan

[f]Research Center for Low Temperature and Materials Sciences, Kyoto University, Kyoto, 606-8502, Japan

Textures of the rotating superfluid ^{3}He-A in a single narrow cylinder have been studied by NMR measurement. Textures are determined by the effects of the wall, the magnetic field, the dipole interaction, the flow of the superfluid and so on. In a narrow cylinder, the characteristic textures such as Mermin-Ho texture[1] can be formed because of the large effect of the wall. A texture shows a characteristic NMR spectrum and we can determine the texture of the observed spectrum by comparing the resonance frequency of NMR spectrum with the calculated one of the spin wave mode[2]. We present the nucleation and the transformation of texture of superfluid ^{3}He-A phase in a single narrow cylinder at various temperature, magnetic field and rotational speed.

1. N. D. Mermin and Tin-Lun Ho, Phys. Rev. Lett. **36**, 594 (1976)
2. T. Kunimatsu *et al*, J. Low Temp. Phys. **171**, 280 (2013)

PS1.13 Spin waves in the B-phase of superfluid ^{3}He in (confined) cylindrical geometry

O.W.B. Benningshof* and R. Jochemsen

Kamerlingh Onnes Laboratory, LION, Leiden University, P.O. Box 9504, 2300 RA Leiden, The Netherlands

We describe experiments on superfluid ^{3}He in a cylinder of 1 mm in diameter. This geometry causes the preferred orientation of the $\hat{\mathbf{n}}$-vector in the superfluid B-phase to be locally different, resulting in a curved configuration across the sample. Exclusive to our experiment is the observation that we succeeded in obtaining a texture which is meta-stable and unchanged in our pressure and temperature ranges, most likely because the experiment is performed at low pressures and low magnetic fields. As this texture can be considered as a potential for spin waves, we had the unique opportunity to study spin waves for several pressures in exactly the same texture. Our geometry causes this texture potential to be nearly quadratic, allowing an analytic solution of the theory which can be compared to our experimental results. As predicted we find the intensities of all spin wave modes more or less equal. Increasing the pressure shows a gradual increase in the number of spin wave modes in our cell.

* Now at: Institute for Quantum Computing, University of Waterloo, Waterloo, Ontario, Canada N2L3G1

PS1.14 A Variable Path Length Cell for Transverse Acoustic Studies of Superfluid ^{3}He

C.A. Collett, J.I.A. Li, A.M. Zimmerman, W.J. Gannon, and W.P. Halperin

Department of Physics and Astronomy, Northwestern University, Evanston, IL 60208, USA.

Transverse acoustic cavities have recently been used to great effect to probe the order parameter structure of superfluid ^{3}He. We have used cavities with thicknesses of tens of microns to explore the acoustic Faraday effect,[1] f-wave interactions,[2] and possible new order parameter collective modes[3] in ^{3}He. The attenuation of transverse sound can approach 1000 cm^{-1} for temperatures increasing toward T_c and at frequencies greater than 100 MHz. In order to explore surface bound states in superfluid ^{3}He-B and to search for transverse sound modes in the normal fluid predicted by Landau[4] in 1957, we require acoustic path lengths of much smaller dimension, on the micron scale, and we need to perform in-situ variations of the cavity spacing. For this purpose we have developed a variable path length acoustic cavity having continuous actuation. Here we describe the design considerations, the unique challenges of our approach, and the physical motivations for our experiments.

[1]Y. Lee *et al.*, Nature **400**, 431 (1999).
[2]C.A. Collett *et al.*, Phys. Rev. B **87**, 024502 (2013).
[3]J.P. Davis *et al.*, Nature Physics **4**, 571-575 (2008).
[4]L.D. Landau, Sov. Phys. JETP **32**, 59 (1957).

PS1.15 Mass Current at a Domain Wall in Superfluid ^{3}He A-Phase

Yasumasa Tsutsumi

Condensed Matter Theory Laboratory, RIKEN, Japan

At a surface of the superfluid ^{3}He A-phase, the surface Andreev bound state accompanied with edge mass current emerges due to a topological phase transition. The direction of the edge mass current is fixed by the direction of l-vector, namely, angular momentum of Cooper pairs. When the surface is specular, angular momentum by the edge mass current points to the direction of l-vector and its amplitude is $N\hbar/2$,[1,2] which is the same with expected value as macroscopic intrinsic angular momentum, where N is number of ^{3}He atoms in a disk system. According to this result, the topological edge mass current seems to relate to the intrinsic angular momentum. Mass current by a topological phase transition also flows at a domain wall in the A-phase, namely, an interface between the A-phases with the opposite direction of l-vector. At the energetically favorable domain wall, we show that the amplitude of the mass current is almost the same with that at the specular surface; however, the mass current flows toward the opposite direction by angular momentum of Cooper pairs. Therefore, we conclude that topological mass current has no relation to intrinsic angular momentum.

1. Y. Tsutsumi and K. Machida, Phys. Rev. B **85**, 100506(R) (2012).
2. J. A. Sauls, Phys. Rev. B **84**, 214509 (2011).

PS1.16 Quasi-classical Theory of the A-phase of Superfluid ^{3}He-A in a Cylinder

K. Nagai

Graduate School of Integrated Arts and Sciences, Hiroshima University, Kagamiyama 1-7-1, Higashi-hiroshima, 739-8521 Japan

We develop a quasi-classical theory to study the A-phase texture with a coreless vortex like the Mermin-Ho texture in a cylinder. We consider both the cases of cylinder with specular surface and diffusive surface. In case of the difusive surface, we find a Mermin-Ho type texture at higher temperatures but with the order parameter suppressed near the surface. In the case of specular surface, however, we find a surface correction to the order parameter. The mass current distribution and the total angular momentum will be also discussed.

PS1.17 Anomalous superflow along an interface between aerogel and superfluid ^{3}He

S. Higashitani[a], H. Takeuchi[b], S. Matsuo[a], Y. Nagato[a], and K. Nagai[a]

[a]Graduate School of Integrated Arts and Sciences, Hiroshima University, Japan

[b]Department of Physics, Osaka City University, Japan

In our previous work[1], we have discussed magnetic response of odd-frequency s-wave Cooper pairs induced around the interface between aerogel and superfluid ^{3}He-B. It was shown that, unlike bulk superfluids, Pauli spin susceptibility is enhanced by the formation of the odd-frequency pairs. In this work, we investigate supercurrent along the aerogel-superfluid ^{3}He-B interface. We find that the supercurrent changes in its direction in the aerogel near the interface, in other words, the proximity-induced pairing state has a "negative" superfluid mass density. We discuss the relation between this phenomenon and odd-frequency paring.

1. Higashitani, S., Takeuchi, H., Matsuo, S., Nagato, Y., and Nagai, K. (2013). "Magnetic Response of Odd-Frequency s-Wave Cooper Pairs in a Superfluid Proximity System", Phys. Rev. Lett. **110**, 175301.

PS1.18 Quasiparticle bound states of vortices in superfluid ^{3}He-B phase

T. Kawakami[a], Y. Tsutsumi[b], and K. Machida[c]

[a] International Center for Materials Nanoarchitectonics (WPI-MANA), National Institute for Materials Science, Tsukuba, Japan

[b]Condensed Matter Theory Laboratory, RIKEN, Wako, Japan

[c]Department of Physics, Okayama University, Okayama, Japan

Superfluid ^{3}He-B phase is known as a topological superfluid, which has zero energy Majorana quasiparticle at an interface between the ^{3}He-B phase and the vacuum[1]. On the other hand, low energy quasiparticle states can be bound at a vortex core, since the order of the ^{3}He-B phase locally disappears.

In the case of the ^{3}He-B phase, the vortex core filled by another superfluid phase of ^{3}He is more stable than the normal core vortex, since they can reduce the condensation energy[2]. For example, so-called v-vortex is stable in the high pressure and the high temperature region, whose vortex core is filled by coexisting phase of the A- and β-phase. The double-core vortex filled by coexisting phase of the planar and polar phase is the ground state at the low pressure and low temperature region.

In this presentation, we will discuss the quantized low energy quasiparticle bound states of the different vortex states of the ^{3}He-B phase on the basis of the numerical solution of the Bogoliubov-de Gennes equation. In this calculations, we use the order parameters obtained by the quasiclassical theory. Finally we clarify that the bound states near the vortex core of the ^{3}He-B phase can be understood as an Andreev bound state of the interface between the vortex core state and the bulk superfluid B-phase.

1. Y. Nagato, S. Higashitani, and K. Nagai, J. Phys. Soc. Jpn. **78**, 123603 (2009).

2. E. V. Thuneberg, Phys. Rev. B **36**, 3583 (1987).

PS1.19 Density and spin–density fluctuations in liquid ^{3}He

T. Lichtenegger[a], R. Holler[a], and E. Krotscheck[a,b]

[a]Johannes Kepler University, Linz, Austria

[b]University at Buffalo–SUNY, Buffalo, New York, USA

A manifestly microscopic theory of the dynamic structure function of strongly correlated fermions at absolute zero is developed. We employ a variational approach in terms of single– and double–pair fluctuations from the correlated ground state to derive and solve equations of motion for density and spin-density fluctuations as measured in neutron scattering off liquid ^{3}He.[1]

Improvement upon recent calculations for the density channel[2] is accomplished by explicitly including exchanges, dynamic interactions and self-energy terms. The resulting dynamic structure function clearly shows the importance of pair fluctuations, *i.e.* intermediate states that cannot be described by the quantum numbers of a single particle, to capture the relevant physics properly.

Within this framework both spin-spin and density-density response functions are obtained in quantitative agreement with experiments.

1. H. R. Glyde *et al.*, Phys. Rev. B 61, 1421 (2000)
2. H. Böhm *et al.*, Phys. Rev. B 82, 224505 (2010)

PS1.20 Effect of Odd-Frequency Cooper Pairing on Pauli Spin Susceptibility in a Superfluid Proximity System

S. Higashitani[a], H. Takeuchi[b], S. Matsuo[a], Y. Nagato[a], and K. Nagai[a]

[a]Graduate School of Integrated Arts and Sciences, Hiroshima University, Higashi-Hiroshima, Japan

[b]Department of Physics, Osaka City University, Osaka, Japan

We report a theoretical study of magnetic response of odd-frequency s-wave Cooper pairs induced in a superfluid proximity system consisting of aerogel and superfluid ^{3}He-B. Using the quasiclassical theory of superfluidity, we analyze Pauli spin susceptibility around the aerogel-superfluid interface. It is shown that the spin susceptibility is enhanced by the formation of the odd-frequency s-wave pairs. As a result, a local peak of the spin susceptibility grows around the interface with decreasing temperature. We discuss how we can detect the odd-frequency pairs via the measurements of the spin susceptibility.

PS1.21 Packed powder as superleak for spin pump experiments in superfluid ^{3}He A_1

N. Kamada[a], A. Yamaguchi[a], G. Motoyama[a], A. Sumiyama[a], T. Sakakibara[b], Y. Aoki[c], Y. Okuda[c], and H. Kojima[d]

[a]Graduate School of Material Science, the University of Hyogo, Japan

[b]Institute for Solid State Physics, the University of Tokyo, Japan

[c]Tokyo Institute of Tecnology, Japan

[d]Serin Physics Laboratory, Rutgers University, USA

Experimental exploration of highly spin-polarized states of liquid ^{3}He by applying external magnetic field is limited by available static magnetic field. In the "ferromagnetic" superfluid A_1 phase of liquid ^{3}He there is an alternate method for boosting spin-polarization by the process of spin pumping[1] without requiring such high magnetic field. The spin pumping in the A_1 phase take advantage of a superleak (SL) acting simultaneously as a filter for both entropy and spin. The spin pump technique that uses the SL-spin filter and a mechanical actuator enables us to directly boost polarization of ^{3}He. The amount of enhancement is spin-polarization has been limited[1] so far. We are now developing a new-type of SL filter made of packed aluminum oxide powder (referred as PAP-SL), in order to achieve greater enhancement of spin polarization. Several kinds of the PAP-SL filter were constructed by pressing aluminum oxide powders into a cylinder holder. The packed powder structures were carefully characterized by a flow-rate-measurement, X-ray tomography, and mercury intrusion porosimetry. The preliminary result shows that the PAP-SL works as SL filter for the superfluid ^{3}He, but the critical current is strongly suppressed compared to a regular cylinder SL filter.

1. A. Yamaguchi, Y. Aoki, S. Murakawa, H. Ishimoto, and H. Kojima, Phys. Rev. B 80, 052507 (2009).

PS1.22 Observation of heterogeneous nucleation in dilute ^{3}He-^{4}He mixtures

I. Gritsenko and G. Sheshin

B.Verkin Institute for Low Temperature Physics and Engineering, Kharkov, Ukraine

Basing on the analysis of experimental data [1,2] we investigate the heterogeneous growth of a new phase in the ^{3}He-^{4}He mixtures at temperature below 300 mK. In [1,2] the supersaturation of superfluid solutions was achieved by various methods. In [1] one has used the dual chamber methodology that allows to change the concentration of the solution at a constant temperature and pressure. In [2] the method was applied of decompression, allowing a supersaturation, changing not only the pressure but also concentration. The temperature dependence and magnitude of supersaturation achievable in both experiments was different. In the papers [3,4] it was shown that the nucleation of a new, concentrated phase of ^{3}He can start on heterogeneous nucleation centers - quantized vortices. In present report we shows that the beginning of a new phase growth is not determined by the degree of supersaturation of the solution but by the values of its concentration, temperature and pressure. Taking into account the dependence of ^{3}He concentration on the line of separation on pressure and the degree of supersaturation obtained in [2], the magnitude of the absolute concentration and temperature in the experiments coincide, forming a curve in the phase diagram which in good agreement with the vortex spinodal, calculated in this paper.

1. V.A. Miheev, E.Ya. Rudavskii, V.K. Chagovets, G.A. Sheshin, JLTP 17, 233 (1991)

2. T. Satoh,M.Marishita, M. Ogata, A. Sawada, T. Kuroda, Physica B 169, 531 (1991)

3. D.M. Jezek, V. Guilleumas, M. Pi, M. Barranco, Phys. Rev. B 51, 11981 (1995)

4. S. Burmistrov, V. Chagovets, L Dubovskii, E. Rudavskii, T. Satoh, G. Sheshin, Physica B 284-288, 321 (2000)

PS1.23 Laser spectroscopy of Ba^+ ions in liquid He: Towards the detection of Majorana fermion surface state in superfluid ^{3}He-B

R. Batulin [a b], P. Moroshkin[a], D. Tayurskii[b], P. Blumhardt[a], P. Leiderer[c], and K. Kono[a]

[a]Low Temperature Physics Laboratory, RIKEN, Japan

[b]Institute of Physics, Kazan Federal University, Russia

[c]Department of Physics, University of Konstanz, Germany

Superfluid ^{3}He-B is predicted to have a gapless Majorana fermion surface state [1]. Recently, it was suggested that this state can be detected in a spin-relaxation experiment using free electrons trapped under the surface of ^{3}He-B [2]. However, the limitations of the method so far precluded the experimental detection of the Majorana fermion surface state.
We develop an alternative technique using the electron spin of the Ba^+ ion as a probe. The ions can be injected in liquid He and trapped in nanometer-sized cavities (atomic bubbles) under the free surface of ^{3}He-B. Our proposal relies on the technique of optically-detected magnetic resonance that is well established for impurity atoms in superfluid He [3]. Polarized resonant laser radiation can be used to spin-polarize the sample of Ba^+ ions. The achieved polarization and its decay caused by the interaction with the surface excitations will then be monitored via the laser-induced fluorescence.
We discuss the advantages and challenges of the proposed experimental approach and present the progress report of our project up to date.

1. Volovik, G., JETP Letters, **90**, 398 (2009).
2. Chung, S.B., Zhang, S.C., Phys. Rev. Lett., **103**, 235301 (2009).
3. Kinoshita, T., Takahashi, Y., Yabuzaki, T., Phys. Rev. B, **49**, 3648 (1994)

PS1.24 The influence of the acoustic radiation on the onset of the turbulent flow in He II

G. Sheshin, R. Nikonkov, and I. Gritsenko

B.Verkin Institute for Low Temperature Physics and Engineering, Kharkov, Ukraine

The experimental study are carried out of the influence of acoustic emission on development of turbulent flow in He II at 350 mK and at various pressures, from the vapor pressure to that of 4He crystallization. The experimental technique of oscillating quartz tuning fork was applied for simultaneous exciting both superfluid flow, near the oscillating tuning fork prongs, and the acoustic wave radiation. The flow rate of He II and the amplitude of the radiated acoustic waves was driven by voltage oscillations which excited the fork prongs. Furthermore, the power of an acoustic wave depends on the density and sound velocity in He II as (ρ/c^5), which in turn depends on the pressure. This allowed to measure the influence of the amplitude of acoustic emission on the flow in He II by changing the pressure. It was found that the decrease in power, emitted by the acoustic wave tuning fork, reduces the critical velocity for the transition from laminar to turbulent flow.

PS1.25 Moved to PS5.27

K. E. Nemchenko[a], Yu. V. Rogov[b], and S. Rogova[a]

[a]Energy Physics Department, Karazin Kharkiv National University, Kharkiv, Ukraine
[b]Research associate 'Accelerator', NSC Kharkiv Institute of Physics and Technology, Kharkiv, Ukraine

PS1.26 The excitations of atoms in helium system

A.I. Karasevskii

Ukrainian Academy of Sciences, Institute for Metal Physics,36 Vernadsky str.,Kiev,03142, Ukraine

It is shown that the atoms in helium crystals and in the liquid helium can be treated as quantum particles localized in potential wells, created by the atomic potentials of the neighboring atoms. As a result, the state of the atoms in the liquid helium characterized by the discrete spectrum of the energy. This leads to the discrete spectrum of atomic excitations, collective nature of which manifests itself in the formation of the s and p bands ground and excited states of helium atoms, separated by a gap [1,2]. Size of the gap is 8.5 K at T = 0 and decrease with increasing temperature. Presence of a gap allows us to draw the analogy between the physical mechanisms of superfluidity and superconductivity.

1. A.I. Karasevskii, V.V. Lubashenko, Phys. Rev. B, 60, 12091 (1999)
2. A.I. Karasevskii, V.V. Lubashenko, J. Low Temp. Phys., 122, 195 (2001)

PS1.27 Simulation of liquid helium-4 in aerogel by means of the density functional theory

D. A. Tayurskii and Y. V. Lysogorskiy

Institute of Physics, Kazan Federal University, Russia

The distribution of the liquid ^{4}He was investigated by means of the density functional theory[1] in the different confined geometries. The following environments were considered: adsorbing and nonadsorbing silica aerogel and homogeneous adsorbing strand. The tendency of helium atoms to adsorb on the concave aerogel surface has been demonstrated. It has been shown that in the confinement with fractional mass dimension within certain scales the liquid helium possesses the fractional mass dimension within these scales too. The dependence of the liquid helium energy on the number of atoms for different type of adsorbing surfaces was investigated as well. It has been found that the specific energy of liquid helium behaves differently in the cases of adsorbing and nonadsorbing external potentials, what indicates the nonextensivity of the system under consideration. Thus the necessity of taking into account the surface effects and the fractional mass dimension in the studies of the properties of liquid helium[2,3] in a restricted space geometry has been demonstrated.

1. Dalfovo F., Lastri A., L. Pricaupenko, S. Stringari (1995), Phys. Rev. B 52, 1193.
2. Tayurskii D.A., Lysogorskii Y.V., Zvezdov D.Y. (2009), J. of Phys.: Conf. Series 150, 032110.
3. Tayurskii D.A., Lysogorskii Y.V. (2009), J. of Low Temp. Phys. 158, 237-243.

PS1.28 Theory of liquid Helium-4 in a deformed Heisenberg space

I.O. Vakarchuk[a] and G. Panochko[b]

[a]Department for Theoretical Physics, Ivan Franko National University of Lviv, Ukraine

[b]College of Natural Sciences, Ivan Franko National University of Lviv, Ukraine

Effective method for studying the Bose liquid is method of collective variables. In this representation the Hamiltonian a system of spinless Bose-particles of mass m each with Cartesian coordinates $\mathbf{r}_1, ..., \mathbf{r}_N$, which are moving in a volume of V, we can write the sum of Hamiltonians infinite set of harmonic oscillators that describe the density fluctuations in a Bose liquid and the sum of contributions from anharmonicity of the vibrations. Difficulties with regard to two and three-particle correlations we throw at deformation commutation relations between the generalized coordinates $Q_{\mathbf{k},\mu}$ and momenta $P_{\mathbf{k},\mu}$:

$$[Q_{\mathbf{k},\mu}, P_{\mathbf{k},\mu}] = i\hbar\sqrt{1 - \beta_k Q^2_{\mathbf{k},\mu}}$$

where the deformation parameter β_k is written via the structure factor S_k of liquid Helium-4 obtained from X-rays scattering measurements. As follows multimode Hamiltonian Bose liquid in the image of collective variables changes of single-mode Hamiltonian and obtain good agreement with the results of perturbation theory for the spectrum of elementary excitations of a Bose liquid.

PS1.29 Spinodal decomposition of two-dimensional ^{3}He at low densities

F. M. Gasparini[a], R. Holler[b], and E. Krotscheck[a,b]

[a]Department of Physics, University at Buffalo, SUNY, Buffalo, New York 14260, USA

[b]Institute for Thoretical Physics, Johannes Kepler University, Linz, Austria

Recent experiments[1] on quasi-two-dimensional ^{3}He absorbed on graphite and on graphite pre-plated with ^{4}He, as well as earlier experiments[2] with ^{3}He on a non-crystalline substrate suggest that there is a liquid-gas phase transition at low densities[3]. The result has received wide attention[4] since it is counter-intuitive because two-dimensional ^{3}He is generally believed to be a gas. Effects like the enhancement of two-particle binding due to the finite width of the ^{3}He holding potential[5] and phonon-exchange are not strong enough to produce sufficient binding which would lead to a condensed phase.

However, in the presence of a substrate, the ^{3}He acquires an effective mass, either from the band structure of the underlying substrate, or from hydrodynamic backflow of ^{4}He. We show that even a small effective mass of $m^* = 1.06 m_{\mathrm{He}_3}$ is, at $T = 0$, sufficient to produce a spinodal instability of the ^{3}He which leads to a condensed phase.

1. D. Sato, K. Naruse, T. Matsui, and Hiroshi Fukuyama, Phys. Rev. Lett. **109**, 235306 (2012).
2. B. Bhattacharyya and F. M. Gasparini, Phys. Rev. Lett. **49**, 919 (1982).
3. A. D. Smart, Physics Today **66**, 15 (2013).
4. V. Grau, J. Boronat and J. Casulleras, Phys. Rev. Lett. **89**, 045301 (2002).
5. S. Kilić, E. Krotscheck, and L. Vranješ, J. Low Temp. Phys. **119** 715 (2000).

PS1.30 Redistribution of 2D Electrons on Liquid Helium under Pulse-Modulated MW Irradiation

L. V. Abdurakhimov, A. O. Badrutdinov, and Denis Konstantinov

Okinawa Institute of Science and Technology (OIST), Japan

Previously the microwave-induced vanishing of magnetoresistance in a two-dimensional electron system (2DES) on the surface of liquid helium was reported: the zero-resistance states (ZRS) were observed under conditions of the resonant intersubband absorption of continuous microwave (MW) irradiation.[1] Recently it was also shown that under periodic on/off switching of MW radiation (pulse-modulated MW irradiation) the transitions into/out of the ZRS regime were accompanied by electron density oscillations – periodic spatial redistribution of electrons from the center to the edge of electron pool.[2] The oscillations were registered by measurement of the electric currents going through top Corbino electrodes capacitively coupled to the 2DES, and consisted of a number of frequency modes, a nature of which was not clear.[3] Here we present results of further experimental investigations of the redistribution effect. Analysis of the data, obtained in experiments with different liquid helium depths, shows that some of the observed frequency modes can be explained by considering the 2DES and the top electrodes of a cell in the frames of an equivalent RLC-circuit model.

1. D. Konstantinov and K. Kono, Phys. Rev. Lett. **103**, 266808 (2009); D. Konstantinov and K. Kono, Phys. Rev. Lett. **105**, 226801 (2010)

2. D. Konstantinov, A. Chepelianskii, and K. Kono, J. Phys. Soc. Jpn. **81**, 093601 (2012)

3. D. Konstantinov, M. Watanabe, and K. Kono, J. Phys. Soc. Jpn., *in press*

PS1.31 The Role of Resonance Conditions at the Edge of 2D Electron Pool in MW-Induced Zero-Resistance States Formation in 2DES on Liquid Helium

L. V. Abdurakhimov, A. O. Badrutdinov, and Denis Konstantinov

Okinawa Institute of Science and Technology (OIST), Japan

The conductivity of a two-dimensional electron system (2DES) on liquid helium subjected to the microwave (MW) excitation at the frequency of surface subband resonance $\omega = \omega_{1\to2}$ exhibits magneto-oscillations governed by the ratio ω/ω_c, where ω_c is the cyclotron frequency.[1] At certain conditions the minima of the magneto-oscillations evolve into zero-resistance states[2] (ZRS) which appear to be very similar to the magneto-oscillations and ZRS effect observed previously in GaAs/AlGaAs heterostructures.[3] The theory shows that the nonequilibrium filling of the second surface subband induced by the MW resonance can be the origin of the negative conductivity which leads to ZRS in 2DES on liquid helium.[4] However, microscopic mechanisms of ZRS formation have still not been fully clarified. Here we present preliminary experimental results showing that the ZRS formation is very sensitive to resonance conditions at the 2DES edge.

1. D. Konstantinov and K. Kono, Phys. Rev. Lett. **103**, 266808 (2009)

2. D. Konstantinov and K. Kono, Phys. Rev. Lett. **105**, 226801 (2010)

3. M.A. Zudov et al., Phys. Rev. B **63**, 201311 (R) (2001); R.G. Mani et al., Nature **420**, 646 (2002); M.A. Zudov et al., Phys. Rev. Lett. **90**, 046807 (2003)

4. Yu.P. Monarkha, Low Temp. Phys. **37**, 655 (2011)

PS1.32 Excitation of Surface Waves by Second Sound Waves in Superfluid Helium-4

L.V. Abdurakhimov[a,b], I.A. Remizov[a], and A.A. Levchenko[a]

[a]Institute of Solid State Physics RAS, Chernogolovka, Russia

[b]Present address: Okinawa Institute of Science and Technology (OIST), Japan

We report results of experimental study of interactions between waves on He-II surface and second sound waves in the bulk He-II in a rectangular container. Surface waves are registered by the optical technique developed previously.[1] Under applying AC electric current of frequency ω to a heater, a second sound wave of frequency $\omega_{ss} = 2\omega$ is excited in the volume of superfluid helium – an oscillating counterflow of normal and superfluid components is developed under the surface. When the heating power is below a critical value, a surface wave is formed at the frequency ω_1 equal to the second sound frequency, $\omega_1 = \omega_{ss}$. Also a number of harmonics at frequencies multiple to ω_1 are observed which can be explained by surface waves nonlinear interactions. Upon increasing of the pumping amplitude above the critical value, an additional subharmonic surface wave is developed at the half frequency $\omega_2 = \omega_1/2$ which is probably due to 3-wave decay instability of the surface wave of frequency ω_1.

1. L. V. Abdurakhimov, M. Yu. Brazhnikov, and A. A. Levchenko, Low Temp. Phys. 35, 95 (2009)

PS1.33 Magneto-Oscillations Induced by Frequency-Modulated MW-Irradiation in 2DES on Liquid Helium Surface

L. V. Abdurakhimov, A. O. Badrutdinov, and Denis Konstantinov

Okinawa Institute of Science and Technology (OIST), Japan

We report about recent progress in investigations of magneto-oscillations induced by microwave (MW) irradiation observed previously in the two-dimensional electron system (2DES) on liquid helium.[1] 2D electron layer was formed on the surface of liquid helium-4 at the temperature of about 0.1 K. Electron transition between the two lowest energy subbands $1 \to 2$ was induced by MW irradiation. In addition, magnetic field was applied perpendicularly to the electron layer which caused Landau quantization of the electron in-plane motion energy. A conductivity of 2DES was measured by Sommer-Tanner technique. The magneto-oscillations were observed which resulted from elastic electron scattering from the excited low number Landau level of the second subband to a high number Landau level of the first subband. Since subbands energy difference depended on holding electric field, dependence of magneto-oscillation magnitude on holding voltage had a resonance form. It was found that the resonance width was two orders greater than expected one which can be attributed to local origin of magneto-oscillations due to electric field spatial inhomogeneity. To overcome this, we used frequency modulated (FM) MW irradiation. Indeed, we observed increase of magneto-oscillations magnitude depending on FM modulation frequency. From this dependence we estimated time of electron energy relaxation from the second subband to the first subband which was found to be of the order of 1 microsecond.

1. D. Konstantinov and K. Kono, Phys. Rev. Lett. **103**, 266808 (2009); D. Konstantinov and K. Kono, Phys. Rev. Lett. **105**, 226801 (2010)

PS1.34 Superfluid Response and Quantum Criticality of Two Dimensional ^{4}He on a Triangular Lattice

J. Nyéki[a], A. Phillis[a], A. Ho[a], D. Lee[b], P. Coleman[c], J. Parpia[d], B. Cowan[a], and J. Saunders[a]

[a]Department of Physics, Royal Holloway University of London, Egham, TW20 0EX, United Kingdom

[b]Blackett Laboratory, Imperial College London, London SW7 2AZ, United Kingdom

[c]Centre for Materials Theory, Department of Physics and Astronomy, Rutgers University, Piscawatay, NJ 08854, USA

[d]LASSP, Department of Physics, Clark Hall, Cornell University, Ithaca, NY 14853, USA

We report the discovery of an anomalous and quantum critical superfluid response in the second atomic layer of ^{4}He adsorbed on the surface of graphite, a system of two dimensional bosons subject to triangular lattice potential. We observe the sudden emergence of superfluid response at a finite layer density. With increasing density the superfluid is tuned towards a quantum critical point, near to layer completion, at which a Mott insulator forms and superfluidity vanishes. The superfluid density exhibits scaling, consistent with a superfluid-insulator transition in the same universality class as the Bose-Hubbard model in the clean limit. The unusual temperature dependence of the superfluid density, and the absence of a clear onset temperature signifies a new state of matter with both superfluid and density wave order.

PS1.35 Cyclotron-resonance-induced dynamics of the electrons-on-helium system

A. O. Badrutdinov, L. V. Abdurakhimov, and D. Konstantinov

Okinawa Institute of Science and Technology, Japan

We report an experimental study of surface electrons on liquid helium-4 under the cyclotron resonance excitation. The observed conductivity response has a structure of two resonant lines, which strongly depends on the excitation intensity and the electron confinement potential. When the excitation intensity is high enough, electrons can partially escape from the potential trap, being significantly overheated by the resonant absorbtion. The transient response of surface electrons to switching the cyclotron resonance excitation on and off reveals complicated dynamics, which includes the electron density redistribution towards the boundaries of the confinement area, as well as the formation of a quasi-3D fraction of electrons. Both conductivity and transient responses are reminiscent of the phenomena observed under the surface state resonance excitation in quantizing magnetic field[1,2].

1. D. Konstantinov and K. Kono, Phys. Rev. Lett. **105**, 226801 (2010)
2. D. Konstantinov, A. Chepelianskii, and K. Kono, J. Phys. Soc. Jpn. **81**, 093601 (2012)

PS1.36 Effects of strong internal forces on microwave-induced magneto-oscillations in surface electrons on liquid helium

D. Konstantinov[a], Yu. P Monarkha[b], and K. Kono[c]

[a]Okinawa Institute of Science and Technology, Japan

[b]Institute for Low Temperature Physics and Engineering, Kharkov, Ukraine

[c]Low Temperature Physics Laboratory, RIKEN, Japan

Microwave-induced oscillations of longitudinal conductivity were recently observed in two-dimensional electron system on the surface of liquid helium.[1] This phenomenon shows striking similarities to microwave-induced resistance oscillations and zero-resistance states observed in high-mobility 2D electron gas in GaAs/AlGaAs heterostructures.[2] A theory was proposed, which explains the appearance of oscillations in the electron system on helium as a result of a new mechanism of momentum relaxation of microwave-excited electrons as they scatter elastically between the excited subband to the ground subband.[3] The theory also predicts strong effects of electron-electron interaction in this system. Here we report on the experimental observation of the predicted many-electron effects on amplitude and phase of magneto-oscillations for electrons on liquid ^{3}He. In particular, we show that observed broadening of the oscillations, shift of the conductivity extremes, and suppression of the zero-resistance states with increasing electron density can be explained by the influence of the internal many-electron fluctuating electric field. Our results provide important evidences in favor of the new relaxation mechanism proposed earlier.[3]

1. D. Konstantinov and K. Kono, Phys. Rev. Lett. **105**, 226801 (2010).
2. R. G. Mani *et al.* Nature **420**, 646 (2002).
3. Yu. P. Monarkha, Fiz. Nizk. Temp. **38**, 451 (2012).

PS1.37 **Superfluid Helium-4 as an Ultra-low Loss Optomechanical Element**
Coupling the motion of superfluid and superconducting condensates

L. De Lorenzo and K. C. Schwab

Applied Physics, Caltech, Pasadena CA, USA

Frictionless motion at zero frequency is a hallmark of superfluidity, which has led us to consider the superfluid state of helium-4 as an ultra-low loss mechanical element for the study of the quantum limits of motion. At temperatures below 500 mK, acoustic loss in first sound at low frequencies occurs through the non-linear mechanical response which leads to a T^4 dependance of the acoustic attenuation coefficient. Our estimates suggest that the quality factor for a kilohertz frequency resonator can approach 10^{11} for temperatures below 10 mK and with a helium-3 isotopic impurity fraction less than 10^{-10}. To detect the superfluid motion with quantum-limited backaction, we have coupled the acoustic motion of a centimeter scale volume of helium-4 to the TE_{011} mode of a cylindrical superconducting niobium microwave resonator (11 GHz resonance with an internal Q of $3.5 \cdot 10^8$), through the pressure dependent modulation of the permitivitty. Using a properly designed microwave detection circuit (sideband resolved, shot noise limited), detection of the motion near the standard quantum limit appears possible. Our first low temperature measurements with this system have demonstrated the parametric coupling between the acoustic motion and the microwave cavity frequency. Realization of an optimized system may allow for careful studies of the lifetimes of quantum states of motion with massive gram scale objects, probing quantum decoherence mechanisms which are speculated to exist for massive objects, and the detection of very weak continuous wave inertial and gravitational forces.

PS1.38 **Quadratic damping of mechanical oscillators and its effect on their resonant response**

D. Schmoranzer[a], M. J. Jackson[a], and J. Luzuriaga[b]

[a]Faculty of Mathematics and Physics, Charles University, Ke Karlovu 3, 121 16, Prague, Czech Republic
[b]Centro Atómico Bariloche, Inst. Balseiro, UNC, CNEA, 8400, Bariloche, Argentina

In the studies of both classical and quantum turbulence, significant attention is devoted to the investigation of the behaviour of various submerged oscillators. Upon entering the turbulent regime, the oscillators start to experience a significant drag force, which is non-linear with the peak velocity. We present a simple model of such a system, derive the limiting cases, and calculate its resonant response at the fundamental frequency as a function of the applied driving force. We apply the model to the crossover from linear to non-linear drag forces and compare with previous models[1] and selected experimental data on the transition to turbulence ^{4}He.

1. E. Zemma & J. Luzuriaga, J. Low Temp. Phys. **172**(3/4), (2013), in print.

PS1.39 Superfluidity of a spin-imbalanced Fermi gas in a three-dimensional optical lattice

M. Fortes[a], R. Mendoza[b], and M.A. Solís[a]

[a]Instituto de Física, Universidad Nacional Autónoma de México, México

[b]Posgrado en Ciencias Físicas, Universidad Nacional Autónoma de México, México

We study fermion pairing in a population-imbalanced mixture of ^{6}Li atomic gas loaded in a three-dimensional lattice at very low temperatures. Using the number equation for each population, the gap equation and the equation for the Helmholtz free energy, we determine the gap, chemical potentials and pair-momentum as functions of polarization. These parameters define the stability regions for a Fulde-Ferrell-Larkin-Ovchinnikov phase; a phase separation region where BCS and normal phases coexist; a Sarma phase when the pair-momentum vanishes, and the transition to the normal phase when the gap disappears. The collective-mode energies are then calculated using a Bethe-Salpeter approach in the general random phase approximation assuming that the system is well described by the single-band Hubbard model. A novel result is that fermionic atomic gas shows a superfluidity behavior revealed by rotonlike minima in the asymmetric collective-mode energy spectrum.

PS1.40 Quantum critical properties in the topological Ginzburg-Landau theory of self-dual Josephson junction arrays

S. Sakhi

College of Arts and Sciences, American University of Sharjah, UAE

I examine the multicritical behavior of a generalized $U(N_1) \times U(N_2)$ Ginzburg-Landau theory containing two multicomponent complex fields which couple differently to two gauge fields described by two Maxwell terms and one mixed-Chern-Simons term. This model is relevant to the dynamics of Cooper pairs and vortices in a self-dual Josephson junction array system near its superconductor-insulator transition. I analyze the renormalization group flow at fixed dimension and obtain the beta functions at one loop when both disorder fields are critical. Two sets of infrared-stable charged fixed points solutions are found for $N > N_c$: partially charged solutions with respect to the gauge fields exists with $N_c = 35.6$, and fully charged solutions exist with $N_c = 12.16$. I show that fine tuning the ratio of the two energy scales in the model has the effect of reducing the critical number N_c and thus enlarges the region where the quantum phase transition is continuous.It is also found that the decoupled fixed point which is stable in the neutral case is no longer attainable in the presence of fluctuating gauge fields. I probe the conductivity at the critical point and show that it has a universal character determined by the renormalization group infrared-stable fixed-point values of the gauge couplings.

1. S. Sakhi, J. Phys. A: Math. Theor. 45 (2012) 175301.

PS1.41 On electrical fields in dielectrics caused by temperature gradient

S. I. Shevchenko

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

In this report I have show that the temperature gradient causes the polarization of dielectrics. The effect is a universal one and it should take place in any dielectrics. The physical nature of this phenomenon consists in that the dipole-quadrupole interaction of the atom in a given lattice site with a neighbouring atom induces the dipole momentum of that atom. In the absence of temperature gradient the summation over all neighbours results in zero dipole momentum. Nonzero temperature gradient results in an appearance of the specific direction in the crystal. It causes the anisotropy of the phonon distribution function and nonzero average dipole momentum. The coefficient of proportionality between the polarization vector and the temperature gradient depends on temperature and it is similar to the temperature dependence of the specific heat. Liquid dielectrics, in particular, superfluid systems, should also demonstrate this phenomenon. In superfluids under the propagation of the second sound (temperature waves) the difference of temperatures results in the difference of electrical potentials.

PS1.42 The Pressure Coefficients of the Superconducting Order Parameters at the Ground State of Ferromagnetic Superconductors

R. Konno[a], N. Hatayama[a], and R. Chaudhury[b]

[a]Kinki University Technical College, Japan

[b]S. N. Bose National Centre for Basic Sciences, Kolkata, India

We investigated the pressure coefficients of the superconducting order parameters at the ground state of ferromagnetic superconductors based on the microscopic single band model by Linder et al.[1,2] The superconducting gaps (i) with the line node and (ii) similar to the ones seen in the thin film of A2 phase in liquid ^{3}He were used. Our numerical results are in qualitative agreement with experimental observations. This study shows that we would be able to estimate the pressure coefficients of the superconducting and magnetic order parameters at the ground state of ferromagnetic superconductors.

1. Linder et al., Phys. Rev. B**76**, 054511 (2007).
2. Linder et al., Phys. Rev. B**77**, 184511 (2008).

PS1.43 **Self-organizing disorder and low-temperature thermal conductivity of molecular crystals**

G. A. Vdovychenko[a], A. I. Krivchikov[a], O. A. Korolyuk[a], J. Ll. Tamarit[b], L. C. Pardo[b], and F. J. Bermejo[c]

[a]B. Verkin Institute for Low Temperature Physics and Engineering of NAS Ukraine, Kharkov, Ukraine

[b]Grup de Caracteritzacio de Materials, Departament de Fisica i Enginyieria Nuclear, ETSEIB, Universitat Politecnica de Catalunya,Barcelona, Catalonia, Spain

[c]Instituto de Estructura de la Materia, CSIC, Madrid and Department of Electricity and Electronics, University of the Basque Country, Bilbao, Spain

The goal of this study was to investigate experimentally the thermal conductivity of simple molecular systems, orientational glasses in the temperature region 2-150 K. The objects were molecular orientational glasses: ethanol (C_2H_5OH), freon 112 ($C_2F_2Cl_4$), freon 113 ($C_2Cl_3F_3$), cyanocyclohexane ($C_6H_{11}CN$), cyclohexanol ($C_6H_{11}OH$) and cyclohexene (C_6H_{10}). The data are analyzed in terms of the presence of several phonon scattering channels contributing to a resistive relaxation rate which apart from anharmonic Umklapp processes requires the implicit account of glassy dynamical features which are here handled in terms of the soft potential model. The analysis of the experimental results on the thermal conductivity of two types of glass - like molecular crystals (orientational glasses) shows that the temperature dependence of the thermal conductivity $\kappa(T)$ in these substances is similar to that of amorphous solids. The thermal conductivity can be described as a sum of two contributions $\kappa(T) = \kappa_I(T) + \kappa_{II}(T)$, where $\kappa_I(T)$ accounts for the heat transfer by long-living acoustic excitations, and $\kappa_{II}(T)$ stands for the heat transfer by delocalized vibrational excitations (diffusons). It is shown that the contribution $\kappa_I(T)$ can be described well by the universal curve in the soft potential model.

PS1.44 **Photo-induced Quantum Phase Transition and Magnetic Solitons in the Perovskite GdSrMnO**

I. Kanazawa, T. Sasaki, and E. Imai

Department of Physics, Tokyo Gakugei University, Tokyo, Japan

Tokura[1] has reported the photo-induced insulator-metal transition in the perovskite PrCaMnO. The photo-excitation above the charge gap in the charge-orbital ordered state can cause the hopping of the electrons or holes into the neighboring site, hence forming magnetic solitons in the regular charge-orbital ordered state. Matsubara et al.[2] have investigated the ultrafast spin and charge dynamics in the course of a photo-induced phase transition from an insulator with short-range charge order and orbital order to a ferromagnetic metal in perovskite-type GdSrMnO.The photo-induced dynamic magnetic effect has been studied in the II-VI-based diluted magnetic semiconductors(DMS) and III-V-based DMS, and interesting phenomena such as the photo-induced magnetic polaron have been discovered. These works stimulated us to the study of the carrier-induced magnetic solitons, which is an interesting and challenging subject. The present author[3] has discussed the insulator-metal transition and large magnetoresistance effects in DMS, using the gauge-invariant Lagrangian density for the photo-induced magnetic solitons. In addition, the present author[4] has discussed the percolation-like insulator-metal transition, the conduction mechanism, and localization of photo-induced magnetic solitons with hole in the perovskite PrCaMnO. In this study, we shall discuss photo-induced insulator-ferromagnetic metal transition and localization of the photo-induced magnetic solitons in the perovskite GdSrMnO, extending the previous formula.

1. Y. Tokura, Physics Today, **56**, 50 (2003) 2. M. Matsubara et al., Phys. Rev. Lett. **99**, 207401 (2007) 3. I. Kanazawa, Phys. Lett. A **355**, 460 (2006) 4. I. Kanazawa, Phys. Status. Solidi B **247**, 644 (2010)

Invited Oral Presentations: Friday August 2nd

P2.1 Quantum turbulence: aspects of visualization and homogeneous turbulence

W. F. Vinen

School of Physics and Astronomy, University of Birmingham, Birmingham B15 2TT, UK

Quantum turbulence is now a mature field of study, which cannot be surveyed easily in a single presentation. The paper will therefore focus on reviews in two areas: the visualization of quantum turbulence, which has the potential to transform our knowledge of the subject; and homogeneous quantum turbulence, which, although much studied, still presents us with interesting and fundamental problems. The latest results based on the use of He_2 metastable excimer molecules as tracers will be presented. Other topics addressed will include the behaviour of the normal fluid in thermal counterflow, fluctuations in vortex-line density, and the mechanisms by which quantum turbulence on a small scale can evolve in various types of flow to a larger scale.

O2.1 Investigation of Quantum Flows of 4He by Visualization and Second Sound Attenuation

L. Skrbek[a], S. Babuin[b], D. Duda[a], M. J. Jackson[a], M. La Mantia[a], M. Rotter[a], J. Šebek[b], D. Schmoranzer[a], and E. Varga[a]

[a]Faculty of Mathematics and Physics, Charles University, Ke Karlovu 3, 121 16 Prague, Czech Republic

[b]Institute of Physics ASCR, v.v.i., Na Slovance, 182 21 Prague, Czech Republic

We report recent experimental investigations of quantum turbulence (QT), using the superfluid ^{4}He in the two-fluid regime ($T \geq 1.2$ K) as a working fluid. We discuss our visualization studies of the Lagrangian dynamics of solid deuterium particles of micron size, focusing on the crossover from quantum to classical behavior of turbulence generated in thermal counterflow. The dynamics of particles of size $d \approx \ell/10$ is studied at length scales $\ell_{\rm exp}$ straddling the average distance ℓ between quantized vortices. The normalized probability distribution (PDF) of the particle velocity changes from the power-law shape typical of QT at scales $\ell_{\rm exp} < \ell$, to the nearly Gaussian form typical of classical turbulent flows at $\ell_{\rm exp} > \ell$. Additionally, the normalized PDF of the particle acceleration at $\ell_{\rm exp} < \ell$, appears consistent with a previously unreported law that predicts a roll-off exponent for the PDF tails. We further report an experimental study of the steady-state and decay of QT generated by a forced flow in a 7 mm wide square duct, with and without silver sinter superleaks and/or obstructing grid (0.5 mm mesh size and 0.1 mm tines). Steady-state flows with a mean velocity of up to 1 m/s are produced by a low temperature bellows, the density of quantized vortex lines is deduced from the attenuation of second sound. We discuss steady state pure superflow, forced pipe superflow, forced grid turbulence and their temporal decays in terms of vortex line density across 4 decades over 200 seconds, containing a robust classical-like power law dependence of the form $t^{-3/2}$. We acknowledge the support of GAČR P203/11/0442.

O2.2 Vortex Emission from Quantum Turbulence Generated in Superfluid ^{4}He

H. Yano

Graduate School of Science, Osaka City University, Japan

Motions of an object immersed in superfluid helium would be only expected to cause superflows around the object; however, motions with a high velocity can generate quantum turbulence in many cases, even at very low temperatures. In experiments, quantized vortices nucleate during cooling through the superfluid transition, remaining attached to surfaces of an helium container and an immersed object. An oscillating object with attached vortices, therefore, generates quantum turbulence and emits vortex rings continuously, by stretching the attached vortices in relative superflows and forming vortex tangles [1].

In the present work, we report the vortex emissions from quantum turbulence generated continuously in superfluid ^{4}He [2]. We used three vibrating wires: two vortex-attached wires for turbulence generation and a vortex-free wire for vortex ring detection, located in parallel with each other. The vortex-free vibrating wire is made of a thin superconducting wire with smooth surfaces [1]. Using this setup, we have investigated time-of-flights of emitted vortex rings. Firstly, we confirmed the characteristics of the vortex detection. The velocities of detected vortex rings are limited to the velocity of the detector wire. Secondly, we have investigated the emission rates of vortex rings for two detector velocities. Vortex rings with lower velocities emit radially from the turbulence, though the emissions seem to be rather anisotropic at higher velocities. Thus the vortex detection using a vortex-free vibrating wire is an efficient way to explore vortex emissions from quantum turbulence.

1. R. Goto, S. Fujiyama, H. Yano, M. Tsubota, *et al.*, Phys. Rev. Lett. **100**, 045301 (2008).
2. Y. Nago, H. Yano, *et al.*, Phys. Rev. B **87**, 024511 (2013).

O2.3 Observation of anomalous momentum distribution in a sample of turbulent BEC obtained by free expansion

V. S. Bagnato

Instituto de Física de São Carlos, University of S. Paulo, São Carlos - SP, Brazil

Recently we have obtained a turbulent cloud of trapped atomic superfluid composed of a Bose-Einstein condensate of Rb atoms held in a magnetic harmonic trap. Vortices in a BEC were generated by an oscillating field generated by a set of coils is superimposed to the trapping field creating displacement, rotation and deformation of the trap potential .Occurrence of Turbulence was evidenced by a changing in the behavior of the hydrodynamics of the sample as well as by the fast proliferation of vortices . The finite size effects on the transition between non-turbulent to turbulent regime was analyzed. At the present work, we show the first evidence of anomalous momentum distribution obtained during a free expansion of the superfluid. During the expansion n(k) can be extracted if a few considerations are made. The most important consideration is related to the validity of the method. During the free expansion of a normal (absence of vortices sample), momentum of expansion results from the strong interaction presented in the sample (Thomas Fermi regime). We however show that for the turbulent cloud that is not the case, and the extra kinetic energy added due to the rotational field is the main cause of the anomalous regime obtained. The will present the technique as well as the results, discussing the possible explanations for the observations.

Work supported by FAPESP and CNPq.

(This work has collaboration of: E. Henn, K. Thompson, R. Shiozaki, M. Caracanhas, F. E. Santos, G. Bagnato, P. Tavares, G. Telles and G. Roati)

O2.4 **Superfluid phases of ^{3}He in a periodic confined geometry[†]**

J. J. Wiman and J. A. Sauls

Department of Physics and Astronomy, Northwestern University, USA

It has long been known that confinement of superfluid ^{3}He on length scales comparable to the superfluid coherence length ξ_0 can stabilize phases not seen in the bulk. Recently, experimental systems with such restricted geometries have emerged that are periodic, or nearly periodic, opening up new possibilities for the study of complex phases in periodic confined geometries.[1] We report theoretical and computational results on the phases and phase diagram of superfluid ^{3}He confined by a two-dimensional periodic array of square boundaries ("posts") with diffusive boundary scattering and translational invariance in the third dimension. Our computational domain is a square region of side length l, with periodic exterior boundary conditions and a square interior boundary of side length $d < l$ with diffusive boundary conditions. The interior boundary reduces the normal-state $SO(3)$ orbital symmetry to the point group D_{4h}. We describe the allowed symmetry classes for the superfluid phases in this geometry. We present results for the phase diagram obtained by numerically minimizing the free energy in Ginzburg-Landau theory formulated with a general 3×3 complex ^{3}He order parameter. For $6 \leq l/\xi_0 \leq 20$, and weak-coupling values of the material parameters, we find a transition (T_{c_1}) from the normal state to a periodic polar phase, for all post dimensions d at which a superfluid transition occurs. For the smaller post dimensions a second transition onsets at a lower temperature, T_{c_2}, to a periodic distorted B phase. There is a critical post dimension above which only the periodic polar phase is stable.

1. N. Zhelev *et al.*, Nanofabricated cells for confined ^{3}He. APS March Meeting 2013, abstract Z22.003.
[†]This research is supported by NSF Grants: DMR-1106315.

O2.5 **Order parameter texture transition in superfluid ^{3}He-B in aerogel**

A. M. Zimmerman, J. I. A. Li, J. Pollanen, C. A. Collett, W. J. Gannon, and W. P. Halperin

Northwestern University

The order parameter of ^{3}He-B is characterized by a relative rotation of the spin and orbital coordinates about a vector $\hat{n}$. Magnetic field $\vec{H}$ and sample boundaries compete to orient $\hat{n}$, resulting in textures observable in experiments. In bulk ^{3}He-B, both the Brinkman-Smith mode (BS) in the texture where the field orients $\hat{n} \parallel \vec{H}$, and a wall-oriented texture (WT), where the competing effect of the boundaries orients $\hat{n}$ at 63.4^o to $\vec{H}$, have been observed.[1,2] In NMR experiments on ^{3}He-B in 98% porosity aerogel, we have observed an abrupt transition between these two textures. We performed experiments on cylindrical aerogel samples characterized to be homogeneous and isotropic, with cylinder axis $\hat{z}$. In isotropic aerogel with $\hat{z} \perp \vec{H}$ we observe BS to be stable down to 1.1 mK. After introducing anisotropy into the sample by elastic mechanical compression ($\approx$ 20%) along $\hat{z}$, we observe a field-independent textural transition from BS to WT at $\approx$ 1.9 mK. In contrast, reorienting the anisotropic sample $\hat{z} \parallel \vec{H}$, we again find a field-independent transition, but now with BS below 1.9 mK and WT at higher temperatures. The lack of dependence of the transition temperature on both magnetic field and sample orientation indicates that aerogel anisotropy plays a dominant role in determining the texture stability in ^{3}He-B.

1. Hakonen , P. J. *et al.* (1989). "NMR and Axial Magnetic Field Textures in Stationary and Rotating Superfluid ^{3}He-B". J. Low Temp. Phys., 76, 225.
2. Ahonen, A. I. *et al.* (1976). "NMR Experiments on the Superfluid Phases of ^{3}He in Restricted Geometries". J. Low Temp. Phys., 25, 421.

O2.6 Parametrically Excited Coherent Roton Aggregates

L. A. Melnikovsky

Russian Academy of Sciences, P.L.Kapitza Institute for Physical Problems, Moscow, Russia

A coherent aggregate of roton pairs in liquid helium around a dielectric resonator can be excited by an electromagnetic field in the microwave range[1,2]. Experimentally, this parametric resonance manifests as an ultra-narrow peak[3,4,5] in the resonator loss at the roton frequency. Coupling of the microwave radiation to the rotons is due to the dependence of individual roton energy ε on the electric field $\mathbf{E}(t)$: $\delta\varepsilon \sim \alpha E(t)^2/2$, where α is the roton polarizability. Elementary process of such parametric excitation is the transformation of two photons into two rotons. Coherence of the emerging roton state means that the electromagnetic resonator and the superfluid around it effectively behave together as a "laser of rotons". This coherence also allows for the phenomenon similar to Josephson effect in superconductors between separate roton reservoirs.

1. L.A. Melnikovsky, *JETP Lett.* **96**, 98 (2012).
2. L.A. Melnikovsky, *JLTP* **171**, 234 (2013).
3. A. Rybalko, S. Rubets, E. Rudavskii *et al.* *Phys. Rev.* **B76** 140503 (2007).
4. A.S. Rybalko, S.P. Rubets, E.Ya. Rudavskii *et al.* *Low Temp. Phys.* **34**, 497 (2008).
5. A.S. Rybalko, S.P. Rubets, E.Ya. Rudavskii *et al.* *Low Temp. Phys.* **35**, 837 (2009).

P2.2 Quantum Magnetism of Cold Atoms in an Optical Lattice

Y. Takahashi

Graduate School of Science, Kyoto University, Japan

First, I give an overview of past and current research on the topic of cold atoms, with special emphasis on the studies of the quantum magnetism of cold alkali atoms in an optical lattice. These include quite recent works on the observation of quantum magnetism of Fermi gas in an optical lattice. I also present some of our recent results towards the study of quantum magnetism for alkaline-earth-like atoms of ytterbium(Yb), such as the formation of an SU(6) Mott insulator of an atomic Fermi gas realized by large-spin Pomeranchuk cooling, the formation of Lieb lattice for the study of flat band ferromagnetism, and a Bose-Fermi dual Mott insulator.

O2.7 Spin-Orbit Coupled Ultracold Atomic Gases

X. Cui

Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China
Institute for Advanced Study, Tsinghua University, Beijing 100084, China

In this talk, I will review several important effects of Spin-Orbit Coupling(SOC) to the properties of ultrocold atomic gases. First, for the fundamental two-body scattering, SOC will lead to mixed scattering between different partial-wave channels, and could also dramatically enhance the low-energy density of state for scattering particles. As a result, SOC can greatly enhance the quantum fluctuation of a Bose condensate, and can even completely destroy a three-dimensional condensate and lead to a super-fragmented quantum state. Finally, I shall discuss the current difficulty for cold atom experiment to generate large SOC using alkalis atoms with Raman lasers , and our recent proposal of utilizing highly magnetic lanthanide atoms to conquer these difficulties. I will also briefly discuss the unique physics associated with spin-orbit coupled lanthanides.

O2.8 Vortex molecules in Bose-Einstein condensates

Muneto Nitta[a], Minoru Eto[b], and Mattia Cipriani[c]

[a]Department of Physics, and Research and Education Center for Natural Sciences, Keio University, Hiyoshi 4-1-1, Yokohama, Kanagawa 223-8521, Japan
[b]Department of Physics, Yamagata University, Yamagata 990-8560, Japan
[c]University of Pisa, Department of Physics “E. Fermi”, INFN, Largo Bruno Pontecorvo 7, 56127, Italy

Stable vortex dimers are known in coherently coupled two component Bose-Einstein condensates (BECs).[1] We construct stable vortex trimers in three component BECs and find that the shape can be controlled by changing the internal coherent (Rabi) couplings.[2] Stable vortex N-omers are also constructed in coherently coupled N-component BECs.[3] We classify all possible N-omers in terms of the mathematical graph theory. Next, we study effects of the Rabi coupling in vortex lattices in two-component BECs. We find how the vortex lattices without the Rabi coupling known before[4] are connected to the Abrikosov lattice of integer vortices with increasing the Rabi coupling.[5] In this process, we find various bound states of vortex dimers at small couplings and vortex dimers changing their partners in various ways at large couplings. We then find that the Abrikosov lattices are robust in three-component BECs.[6]

1. K. Kasamatsu, M. Tsubota and M. Ueda, Phys. Rev. Lett **93**, 250406 (2004).
2. M. Eto and M. Nitta, Phys. Rev. A **85**, 053645 (2012) [arXiv:1201.0343 [cond-mat.quant-gas]].
3. M. Eto and M. Nitta, arXiv:1303.6048 [cond-mat.quant-gas].
4. K. Kasamatsu, M. Tsubota and M. Ueda, Phys. Rev. Lett. **91**, 150406 (2003).
5. M. Cipriani and M. Nitta, arXiv:1303.2592 [cond-mat.quant-gas].
6. M. Cipriani and M. Nitta, arXiv:1304.4375 [cond-mat.quant-gas].

O2.9 The Higgs amplitude mode in a superfluid of Dirac fermions

S. Tsuchiya[a], R. Ganesh[b], and T. Nikuni[a]

[a]Department of Physics, Faculty of Science, Tokyo University of Science, 1-3 Kagurazaka, Shinjuku-ku, Tokyo 162-8601, Japan
[b]Institute for Theoretical Solid State Physics, IFW Dresden, PF 270116, 01171 Dresden, Germany

We study the Higgs amplitude mode in the s-wave superfluid state on the honeycomb lattice [1]. The attractive Hubbard model on the honeycomb lattice was found to exhibit a quantum phase transition between semi-metal and s-wave superfluid phases [2]. We find evidence for a stable Higgs amplitude mode below the two-particle continuum together with a gapless Anderson-Bogoliubov (AB) mode in the vicinity of the quantum critical point. We also find stable collective modes which have "Cooperon" and exciton character in the semi-metal phase. These collective modes are accommodated within a window in the two-particle continuum, which arises as a consequence of the linear Dirac dispersion on the honeycomb lattice. Cooperon and exciton smoothly evolve across the quantum critical point and hybridize into the Higgs mode and the AB mode following Cooperon condensation. We discuss possibility of observing the Higgs mode by Bragg spectroscopy measurements.

1. Tsuchiya, S., Ganesh R., and Nikuni, T. (2013). "The Higgs mode in a superfluid of Dirac fermions". arXiv:1303.3343.
2. Zhao, E. and Paramekanti, A. (2006). "BCS-BEC Crossover on the Two-Dimensional Honeycomb Lattice". Phys. Rev. Lett. 97, 230404.

O2.10 Energy Dissipation in Nano-electro-mechanical Devices at Millikelvin Temperatures

M. Defoort, K. J. Lulla, C. Blanc, O. Bourgeois, and E. Collin

Institut Néel
CNRS et Université Joseph Fourier,
BP 166, 38042 Grenoble Cedex 9, France

We report on experiments performed at dilution temperatures on nano-electro-mechanical goalpost devices [1]. The structures are made of silicon covered with a thin layer of aluminum, and resonate around 10 MHz in their first flexural mode. We have measured in vacuum ($P < 10^{-6}$ mbar) and under small magnetic fields ($B < 1$ T) the mechanical intrinsic dissipation experienced by the device in this first mode, for both the normal and superconducting states of its metallic coating. In the superconducting state, strong nonlinear effects have been discovered. Furthermore, the damping in the superconducting state becomes much smaller at low temperatures than in the normal state, proving that conduction electrons play a key role in the dissipation mechanism. The dissipative component becomes vanishingly small at very low temperatures in the superconducting state, leading to Q factors of about a million, which is exceptional for such small silicon structures.

[1] K.J. Lulla et al., *Phys. Rev. Lett.* **110**, 177206 (2013).

O2.11 Developing Magnetic Resonance Spectroscopic Imaging ULTMRSI to study inhomogeneous texture in Superfluid ^{3}He

M. Kanemoto[a], J. Kasai[a], and Y. Sasaki[a,b]

[a]Department of Physics, Grad. School of Science, Kyoto University, Kyoto, JAPAN
[b]Research Center for Low Temperature and Materials Sciences, Kyoto University, Kyoto, JAPAN

A new class of technology in ULTMRI measurement to study inhomogeneous order parameter in superfluid ^{3}He is developed. Oridinary MRI measurement gives spin density distribution in the NMR sensing area. In conbination with multiple-pulsed NMR measurement, one could also obtain spatial distribution of magnetization due to spin relaxation, spin diffusion, etc. Recently we succeded in developing new maeasurement scheme, with which we can obtain spatial distribution of the resonance frequency shift. This new class of technology in MRI is named as ULTMRSI, which is the abbreviation of Ultra Low Temperature Magnetic Resonance Spectroscopic Imaging.
Thanks to this feature, we obtain a tool to observe real space image of the texture in superfluid ^{3}He. A capability of this new technology will be shown.

O2.12 Development and comparison of two different types of dry dilution refrigerator

T. Hata, T. Matsumoto, K. Obara, H. Yano, and O. Ishikawa

Graduate School of Science, Osaka City University, Japan

Dilution refrigerator is necessary for solid state physics and quantum fluid physics as a tool to produce below 0.3K. We have to recharge liquid helium every a few days and consume a lot of liquid helium in conventional dilution refrigerator. Dry dilution refrigerators, however, do not need liquid helium and can be operated automatically. In near future, therefore, conventional dilution refrigerator will be replaced by dry one due to the easy operation, maintenance free and conservation of helium resources. We have developed two different types of dry dilution refrigerator. One is directly cooled by pulse tube refrigerator in a same cryostat using copper thin wires as a thermal link, and another is cooled by separated GM refrigerator using circulating helium gas through a flexible syphon tube. The latter has been developed for vibration free dry dilution refrigerator. We will compare these two different types of dry dilution refrigerator about several key points: base temperature, precooling time, minimum temperature, helium three circulation rate and cooling power.

Poster Presentations: Friday August 2nd

PS2.1 Quantum Turbulence Produced by Uniformly Moving Grid in ^{4}He in the T=0 Limit

D. E. Zmeev[a], F. Pakpour[b], P. M. Walmsley[b], A. I. Golov[b], P. V. E. McClintock[a], S. N. Fisher[a], W. Guo[c], D. N. McKinsey[d], G. G. Ihas[e], and W. F. Vinen[f]

[a]Department of Physics, Lancaster University, Lancaster, UK[b]School of Physics and Astronomy, The University of Manchester, Manchester, UK[c]Mechanical Engineering Department, Florida State University, Tallahassee, Florida, USA[d]Department of Physics, Yale University, New Haven, Connecticut, USA[e]Department of Physics, University of Florida, Gainesville, Florida, USA

[f]School of Physics and Astronomy, University of Birmingham, Birmingham, UK

Uniform flow through a grid is widely recognized in classical fluid dynamics as the benchmark for creating homogeneous isotropic turbulence. A similar standard, which can be used at very low temperatures, has been eagerly awaited in the field of quantum turbulence. We have designed and built an apparatus that allows a grid to be pulled at constant velocities of up to 20 cm/s through a channel filled with superfluid ^{4}He below 100 mK. We probe the turbulence produced by the motion of the grid by measuring the vortex line density, which is achieved by observing attenuation of the signal from charged vortex rings propagating across the channel volume. The decay of turbulence produced in this way is compared to the dissipation of turbulence created by impulsive spin-down[1] of the same channel from uniform rotation to rest and also turbulence created by intense ion injection into the experimental volume.

1. P. M. Walmsley, A. I. Golov, H. E. Hall, A. A. Levchenko, and W. F. Vinen, Phys. Rev. Lett. **99**, 265302 (2007)

PS2.2 Superfluid counterflow turbulence in short channels

L. Saluto[a], D. Jou[b], and M.S. Mongiovi[a]

[a]Dipartimento di Energia, ingengneria dell'Informazione e modelli Matematici (DEIM), Università degli studi di Palermo, Palermo, 90128, Italy

[b]Departament de Física, Universitat Autònoma de Barcelona, Bellaterra, 08193, Catalonia, Spain

Counterflow superfluid turbulence in cylindrical channels is usually described by assuming that the channel is sufficiently long for the velocity profiles to correspond to a fully developed situation, with vanishing radial flows, and only longitudinal flows. However, for channels with a length shorter than 0.05 $ReyD$, with D the diameter of the channel and Rey the Reynolds number $Rey = VD/\nu$, V being the average velocity of the normal component and ν its kinematic viscosity, the velocity profile has not yet arrived to the fully developed regime. This situation is often found in actual counterflow experiments. In this region, temperature gradient at a given heat flux is higher than that in a fully developed regime[1]. In this poster we present recent results of viscous entrance-flow theory[2] applied to the velocity profile of the normal component in turbulent counterflows and explore some of its difference with the results in the fully-developed region.

1. Lesniewski T.K., Frederking T.H.K. and Yuan S.W.K. (1996). Cryogenics **36**, 203.
2. Lautrup B. (2005), Physics of continuous matter : exotic and everyday phenomena in the macroscopic world. Institute of Physics, Bristol.
3. Mongiovi M.S. (1993). Phys. Rev. B **48**, 6276.
4. Saluto L., Mongiovi M. S. and Jou. D. (to appear) *Longitudinal counterflow in turbulent liquid helium: velocity profile of the normal component*, ZAMP.

PS2.3 Vortex diffusion in axial quantum turbulence

L. Saluto[a], D. Jou[b], and M.S. Mongiovi[a]

[a]Dipartimento di Energia, ingengneria dell'Informazione e modelli Matematici (DEIM), Università degli studi di Palermo, Palermo, 90128, Italy

[b]Departament de Física, Universitat Autònoma de Barcelona, Bellaterra, 08193, Catalonia, Spain

We study the influence of vortex diffusion on the evolution of inhomogeneous quantized vortex tangles. As an illustration, we obtain solutions for these effects in axial counterflow between two concentric cylinders at different temperatures. The vortex diffusion from the inner cylinder to the outer cylinder increases the vortex length density everywhere as compared with the non-diffusive situation. The possibility of hysteresis cycles of vortex line density under variations of the heat flow is explored.

1. Nemirovskii S.K. (2013) Phys. Rep. **524**, 85.
2. Tsubota, M., Kobayashi M. and Takeuchi H. (2012) Phys. Rep. **522**, 191.
3. Tsubota M., Araki T. and Vinen W.F. (2003) Physica B **224**, 329.
4. M. S. Mongiovi and D. Jou (2007) Phys. Rev. B **75**, 024507.
5. L. Saluto (2012) Boll. Mat. Pur. Appl. **vol. V**, 139.

PS2.4 Quantum Turbulence Decay Observations in a Black Body Radiator

D.I. Bradley, S.N. Fisher, A.M. Guénault, R.P. Haley, G.R. Pickett, M. Sarsby, M. Skyba, V. Tsepelin, and P. Williams

Lancaster Univeristy, Lancaster, United Kingdom

Classical turbulence is one of the most complicated and least understood phenomena in Nature. Detection of the energy released by the decay of classical turbulence [in conventional fluids] is extremely difficult due to the small energy release compared to the thermal energy of the liquid. However in a stationary condensate of pure He^3–B at temperatures much less than the superfluid transition temperature, the energy from the decay of turbulence is easily accessible as this comprises almost the entire free energy of the superfluid He^3 condensate. This energy produces readly detectable quasiparticles enabling us to use vibrating wire resonator techniques to measure the energy released by the decaying quantum turbulence.

In this poster we probe the time and power dependencies of turbulence generated by a low frequency oscillating grid in a black body radiator immersed in superfluid He^3–B at several pressures between 2.1 bar and 8.6 bar. We have performed over 700 grid pulses with different grid velocities and pulse lengths while measuring the heat released within the black body radiator. From this, we are able to infer the energy of the turbulence being created by the grid motion and watch its subsequent decay in time.

We present data on transition between Vinen and Kolmogorov like decays as a function of grid velocity.

PS2.5 Observations of vortex emissions from superfluid ^{4}He turbulence at high temperatures

S. Oda, Y. Wakasa, H. Kubo, K. Obara, H. Yano, O. Ishikawa, and T. Hata

Graduate School of Science, Osaka City University, Osaka, Japan

An immersed object with high velocity oscillations can generate a quantum turbulence in superfluid ^{4}He, even at very low temperatures. The continuously generated turbulence would emit many vortex rings with a self-induced velocity inversely proportional to a ring size from a turbulent region corresponding to an oscillating region. Time-of-flight measurements of vortex rings, therefore, are an efficient technique to explore the quantum turbulence with respect to vortex emissions. In the present work, we investigate vortex emissions from quantum turbulence in superfluid ^{4}He at high temperatures, by using three vibrating wires as a turbulence generator and vortex detectors. Two detector wires were mounted around a generator wire: one in parallel and the other in perpendicular to the oscillation direction of the generator. Time-of-flights of vortex rings show an exponential distribution with a non-detection period t_0 and a mean detection period t_1. The non-detection period includes a generation time of a fully developed turbulence and a time-of-flight of a vortex ring [1]. At high temperatures, non-superfluid component as a viscid fluid may dissipate quantized vortices in the superfluid, resulting that only large sizes of rings are reachable to a detector. Using this method, we will report the anisotropy of vortex emissions and a turbulent region with respect to both sizes and detection rates of reachable vortex rings.

1. Y. Nago, A. Nishijima, H. Kubo, T. Ogawa, K. Obara, H. Yano, O. Ishikawa, and T. Hata: Phys. Rev. B 87, 024511 (2013).

PS2.6 Emission of small vortex loops due to reconnections of quantized vortices in superfluid ^{4}He at low temperatures

P. M. Walmsley, D. E. Zmeev, M. J. Fear, and A. I. Golov

School of Physics and Astronomy, The University of Manchester, Manchester, M13 9PL, United Kingdom

We present evidence for small vortex rings emitted upon vortex-vortex reconnections. In one experiment, pairs of charged vortex rings of nearly the same radius and direction of propagation collided resulting in creation of both smaller and larger vortex rings. In the second experiment, small vortex rings with large mean free path were frequently generated within a dense charged vortex tangle, but only at temperatures below 0.7 K, providing insight into the quantum regime of superfluid turbulence.

PS2.7 Interaction of Excimer He_2^* Molecules with Vortex Lines in Superfluid ^4He at $T < 0.2$ K

D. E. Zmeev[a], F. Pakpour[a], P. M. Walmsley[a], A. I. Golov[a], W. Guo[b], D. N. McKinsey[c], G. G. Ihas[d], P.V. E. McClintock[e], S. N. Fisher[e], and W. F. Vinen[f]

[a]School of Physics and Astronomy, The University of Manchester, Manchester M13 9PL, UK

[b]Mechanical Engineering Department, Florida State University,Tallahassee, Florida 32310-6046, USA

[c]Department of Physics, Yale University, New Haven, Connecticut 06520-8120, USA

[d]Department of Physics, University of Florida, Gainesville, Florida 32611-8440, USA

[e]Department of Physics, Lancaster University, Lancaster LA1 4YB, UK

[f]School of Physics and Astronomy, University of Birmingham, Birmingham B15 2TT, UK

We have studied the interaction of metastable spin-triplet He_2^* molecules with quantized vortices in superfluid ^{4}He in the zero temperature limit. The molecules were generated during an injection of electrons from a sharp metal tip at high voltage, and detected as current into a metal collector after their ionization in high electric field. The molecules were only detected at temperatures $T < 0.2$ K. The presence of ^{3}He impurities at the level of 0.3 ppb strongly suppressed the detected signal; the temperature dependence of the detected signal revealed a sharp peak, most probably associated with the condensation of ^{3}He atoms on vortex cores. The vortices were created by either rotation or ion injection.The trapping diameter of the molecules on quantized vortices was found to be 96 ± 6 nm at pressure of 0.1 bar and 27 ± 5 nm at 5.0 bar. We have also demonstrated that a moving tangle of vortices can carry the molecules through the superfluid helium [1].

1. D. E. Zmeev et al., Phys. Rev. Lett. 110, 175303 (2013).

PS2.8 Dynamics of a particle and a quantized vortex at zero temperature : self-consistent calculation

N. Yamasaki[a] and M. Tsubota[a,b]

[a]Department of Physics, Osaka City University, Japan

[b]The OCU Advanced Research Institute for Natural Science and Technology (OCARINA), Osaka City University, Japan

Many experiments for visualizing quantized vortices and normal fluid flow have been performed in superfluid ^{4}He. Recently, metastable He_2 excimer molecules are used as tracer particles[1]. As their radius is only about 10^{-10}m, they hardly perturb the system, thus being a good candidate of tracer particles. In order to understand the interactive motion of He_2 molecules and vortices at zero temperature, we numerically study the trapping diameter by using the self-consistent equations of motions. We calculated the trapping diameter as a function of the initial velocity of the particle. The trapping diameter is almost inversely proportional to the initial velocity of the particle and compared with the observation.

1. D. E. Zmeev et al, *Phys. Rev. Lett.* **110**, 175303, (2013).

PS2.9 Dynamics of the Cluster of Vortex Points in Two-Dimensional Superfluid ^{4}He

A. Nakatsuji[a] and M. Tsubota[a,b]

[a]Department of Physics, Osaka City University, Japan

[b]The OCU Advanced Research Institute for Natural Science and Technology (OCARINA), Osaka City University, Japan

We have simulated the dynamics of cluster of quantized vortex points with the same circulation in two-dimensional superfluid ^{4}He. In two-dimensional quantum turbulence, vortices are always distributed uniformly, but often form some clusters[1]. We study the dynamics of a cluster at zero temperature and finite temperatures. At zero temperature, the cluster only rotates. On the other hand, at finite temperatures, the vortices form a vortex lattice and diffuse with reducing the energy because of mutual friction which works as the repulsive interaction between the same circulation vortices. We investigate for the structure function for the vortex lattice formation.

1. Ashton S. Bradley and Brian P. Anderson Phy. Rev. X **2**, 041001 (2012)

PS2.10 Andreev scattering in turbulent ^{3}He-B: a three-dimensional numerical analysis

Y. A. Sergeev[a], N. Suramlishvili[b], C. F. Barenghi[c], A. W. Baggaley[d], S. N. Fisher[e], V. Tsepelin[e], and G. R. Pickett[e]

[a]School of Mechanical and Systems Engineering, Newcastle University, Newcastle upon Tyne, and Joint Quantum Centre Durham-Newcastle, United Kingdom

[b]School of Mathematics, Bristol University, Bristol, United Kingdom

[c]School of Mathematics and Statistics, Newcastle University, Newcastle upon Tyne, and Joint Quantum Centre Durham-Newcastle, United Kingdom

[d]School of Mathematics and Statistics, University of Glasgow, Glasgow, United Kingdom

[e]Department of Physics, Lancaster University, Lancaster, United Kingdom

We present a theoretical and numerical study of the Andreev scattering technique used for detection of quantized vortex structures in turbulent superfluid ^{3}He-B. We develop a numerical technique for the analysis of the Andreev reflection of quasiparticle excitations by a dense, three-dimensional vortex tangle. We analyze the integral reflection coefficient as a function of the vortex line density and discuss the rôle of screening mechanisms which strongly affect the total reflectivity of the tangle. Analysing the spectral properties of fluctuations of the Andreev-retroreflected signal and comparing them with those of the vortex line density, we find that the spectral densities of fluctuations of both quantities are strongly correlated and obey the same power law. Finally we discuss the implications of our results for the interpretation of quantum turbulence experiments in ^{3}He-B.

PS2.11 Anomalous damping of a low frequency vibrating wire in superfluid ^{3}He-B due to vortex shielding

C. R. Lawson, D. I. Bradley, M. J. Fear, S. N. Fisher, A. M. Guénault, R. P. Haley, G. R. Pickett, R. Schanen, and V. Tsepelin

Department of Physics, Lancaster University, United Kingdom

We have investigated the behaviour of a low frequency vibrating wire in the B phase of superfluid ^{3}He at zero pressure and temperatures from $0.15\,T_C$. The vibrating wire has a goalpost shape with a 25 mm leg length and 8 mm crossbar. It has a deliberately low Q and low resonant frequency of around 60 Hz. Placed in a vertical magnetic field of ≈ 100 mT, it is forced into oscillatory motion by passing an ac current through the wire. Its velocity can be inferred from the ac Faraday voltage generated as the crossbar sweeps through the magnetic field. At low velocities the motion of the wire is impeded by its intrinsic (vacuum) damping and by the scattering of thermal quasiparticles. At higher velocities we would normally expect the motion to be further damped by the creation of quantized vortices and broken Cooper pair excitations. However, for a range of temperatures, as we increase the driving force we observe a sudden decrease in the damping of the wire. We speculate that the wire is shielded from thermal quasiparticles by quantized vortex lines created by the wire itself, and estimate the line density of the turbulent tangle.

PS2.12 Switching Behaviour of a Quartz Tuning Fork in Superfuid ^{4}He

C. R. Lawson, D. I. Bradley, M. J. Fear, S. N. Fisher, A. M. Guénault, R. P. Haley, G. R. Pickett, R. Schanen, V. Tsepelin, and L. A. Wheatland

Department of Physics, Lancaster University, United Kingdom

Here we report our observations of hysteresis and switching between linear and non-linear damping at temperatures below 10 mK for a quartz tuning fork immersed in superfluid ^{4}He and driven at resonance. We associate linear damping with laminar flow around the prongs of the fork, and non-linear damping with the production of vorticity in a “turbulent” regime. By controlling the prong velocity we have observed metastability of both the laminar and the turbulent flow states, and present measurements of the lifetime of each state as a function of the fork velocity.

PS2.13 Energy dissipation and librating motion of superfluid ^{3}He-B in the $T \to 0$ limit

J. T. Mäkinen[a], V. B. Eltsov[a], P. J. Heikkinen[a], J. J. Hosio[a], P. M. Walmsley[b], and V. Zavyalov[a]

[a]O.V. Lounasmaa Laboratory, Aalto University, Finland

[b]School of Physics and Astronomy, University of Manchester, United Kingdom

One of the challenges of the modern research on the dynamics of quantized vortices is the identification of dissipation mechanisms in superfluids with almost no normal component. It is generally believed that the essential role in the dissipation is played by the energy cascade of Kelvin waves, helical excitations on vortex lines, which transfers the kinetic energy from the macroscopic scales larger than the intervortex distance to small scales where the microscopic dissipation mechanism like quasiparticle emission by vortex cores terminates the cascade. So far the experimental verification of this picture is missing. We have studied the librating motion of a cylindrical sample of the superfluid ^{3}He-B, that is rotation of the sample around its axis with a periodically modulated angular velocity, in the temperature range $0.14 - 0.20T_c$. The modulation excites inertial waves in the liquid and Kelvin waves on vortex lines as seen from the decrease of vortex polarization. The polarization is determined from its influence on the order-parameter texture, probed by Bose-Einstein condensates of magnon quasiparticles. When the modulation of rotation velocity is stopped, the energy stored in the inertial waves is dissipated and the vortex polarization is restored. By calibrating the energy using the known free energy difference in solid-body rotation at different velocities we can extract the dissipation rate per vortex line in absolute units. We present dissipation measurements as a function of temperature, pressure, and rotation velocity, and discuss the relation of our results to the picture of the Kelvin-wave cascade.

PS2.14 Design and Characterisation of a Detector for Quasiparticle and Quantum Turbulence Imaging Studies in Superfluid ^{3}He

E. Guise, S. Ahlstrom, D.I. Bradley, S.N. Fisher, A.M. Guénault, R.P. Haley, G.R. Pickett, M. Poole, R. Schanen, V. Tsepelin, and A. Woods

Department of Physics, Lancaster University, UK

We have developed a quasiparticle video camera to visualise vortex dynamics in the pure quantum regime of superfluid ^{3}He-B. At such low temperatures vorticity can be non-invasively probed by ballistic quasiparticles, which are Andreev scattered by vortices. When illuminated by a beam of quasiparticles, a tangle of vortices (quantum turbulence) will cast a shadow. Each pixel of the camera will measure the local quasiparticle density, proportional to the incident flux. This should allow us to make crude images of quantum turbulence, with both time and spatial resolution.

The camera contains twenty-five pixels formed by custom-made 1-D arrays of miniature quartz tuning forks. Each array contains five forks of $50\,\mu$m thickness. All the forks have a tine width of $90\,\mu$m and lengths varying from $1400\,\mu$m to $1900\,\mu$m to give each a unique and well-separated resonant frequency ranging from 20kHz to 40kHz. Five such arrays have been mounted in a copper block to create the camera.

The camera design, characterisation and early results will be presented.

PS2.15 Damping of Mechanical Oscillators During the Turbulent Transition in ^{4}He

M. J. Jackson[a], D. Schmoranzer[a], T. Skokánková[a], J. Šebek[b], E. Collin[c], M. Defoort[c], S. Dufresnes[c], H. Godfrin[c], J. Luzuriaga[d], and L. Skrbek[a]

[a]Faculty of Mathematics and Physics, Charles University, Ke Karlovu 3, 121 16 Prague, Czech Republic

[b]Institute of Physics ASCR, v.v.i., Na Slovance, 182 21 Prague, Czech Republic

[c]Institut Néel CNRS & Université Joseph Fourier, BP 166, F-38042 Grenoble Cedex 9, France

[d]Centro Atómico Bariloche, Inst. Balseiro, UNC, CNEA, 8400, Bariloche, Argentina

We present our most recent findings on the transition to turbulence in both normal and superfluid ^{4}He, including pure quantum turbulence at very low temperatures. We have studied the transition to both classical and quantum turbulence using quartz tuning forks, double-paddle and micro-mechanical goalpost structures[1]. We investigate the differences between the transition to classical turbulence in normal He as well as the transition to quantum turbulence in the superfluid phase. We discuss the changing characteristics of the dependence of the drag coefficient as a function of velocity with varying normal fluid and superfluid fractions. The oscillators' non-linear behaviour at high velocities was measured and compared to models of the non-linear drag force.[2]

1. E. Collin, Y.M. Bunkov and H. Godfrin, Phys. Rev. B **82**, 235416 (2010)

2. E. Zemma and J. Luzuriaga, J. Low Temp. Phys. **172**(3/4), (2013) In Press

PS2.16 Frequency Dependence of the Transition to Quantum Turbulence in Superfluid ^{4}He

A. Woods[a], S.L. Ahlstrom[a], D.I. Bradley[a], M. Človečko[b], S.N. Fisher[a], A.M. Guénault[a], E. Guise[a], R.P. Haley[a], O Kolosov[a], P.V.E McClintock[a], G.R. Pickett[a], M. Poole[a], R. Schanen[a], and V. Tsepelin[a]

[a]Department of Physics, Lancaster University, UK

[b]Present Address: Slovak Academy of Sciences, Kosice, Slovakia

Mechanical resonators such as vibrating wires and tuning forks are widely used for the study of quantum fluids. Here we use an array of custom-made quartz tuning forks. Each fork in the array is nominally identical to the other forks, except for the prong lengths which vary to give a range of fundamental resonance frequencies from 6 kHz to 160 kHz. This allows us to study the frequency dependence of fluid properties for nominally identical geometries.

We have measured the response of the tuning forks in superfluid ^{4}He over a wide range of velocities spanning the transition to turbulence. We compare measurements over the full temperature range, showing how the behavior evolves from classical fluid flow in normal helium above 2.2 K, through the two-fluid regime at intermediate temperatures, to pure quantum turbulence at the lowest (mK) temperatures. We show that for temperatures below 0.8 K where the normal fluid is a gas of ballistic phonons, the normal fluid drag is unaffected by quantum turbulence and the turbulent drag is independent of temperature. At higher temperatures the turbulent drag steadily increases towards the classical drag measured in normal helium.

We present measurements of the critical velocity for the nucleation of quantum turbulence and find that $v_c \approx \sqrt{\kappa\omega}$. We also show measurements of the turbulent drag at low temperatures for a wide range of frequencies.

PS2.17 Numerical and statistical analysis of pure superflow

M. Sciacca[a] and L. Galantucci[b]

[a]Dipartimento SAF, Universitá di Palermo, Italy

[b]Dipartimento Ingegneria Strutturale, Politecnico di Milano, Italy

The recent developments of new technologies, for the experimental visualization of the normal component profile in helium II by mean of metastable helium molecules[1], have suggested numerical studies for a deeper understanding of the mutual interaction between quantum turbulence and normal component. Here we present our recent numerical studies regarding the mutual interplay between the superfluid vortex points and the flow of the normal component in a 2D He II channel superflow. The channel is characterized by the presence of two slippery walls, parallel to the direction of the flow, for the superfluid component, and a bounded domain for the normal component (i.e the normal flow out of the domain is forbidden)[2]. The further assumption is the presence of many vortex points $N_1 = 1876$ and $N_2 = 4800$ (in counterflow they would mimic the TI and TII status, respectively), whose dynamics is ruled by the lagrangian Schwarz's model[3] and whose number is kept fixed because we are interested to the steady state.

More in detail, we present the distribution of the vorticity of the normal component all over the channel, and the statistical analysis (PDF) for the flow of the normal component and the superfluid flow.

1. Guo, W.; Cahn, S.B.; Nikkel, J.A.; Vinen, W.F.; McKinsey, D.N. (2010). Phys. Rev. Lett. **105**, 045301.

2. Babuin S.;,Varga E.; Stammeier, M.; Skrbek, L.; (2013) pp 551-562.

3. Schwarz, K. (1988). Phys. Rev. B **38**, 2398.

PS2.18 Numerical experiments on a two dimensional counterflow channel in helium II by means of a one-fluid model

M. Sciacca[a], L. Galantucci[b], and D. Jou[c]

[a]Dipartimento SAF, Universitá di Palermo, Italy

[b]Dipartimento Ingegneria Strutturale, Politecnico di Milano, Italy

[c]Departament de Física, Universitat Autònoma de Barcelona, Bellaterra, Catalonia, Spain

Superfluid helium is usually described by the two-fluid model proposed by Tisza and Landau with normal and superfluid components, with densities ρ_n and ρ_s and velocities $\mathbf{v}_n$, $\mathbf{v}_s$. An alternative model is a one-fluid model based on ρ, $\mathbf{v}$, T and $\mathbf{q}$ (total density, average velocity, temperature, and heat flux)) which was proposed by means of the Extended Thermodynamics [1]. Both descriptions are related; because $\rho = \rho_s + \rho_n$, $\rho\mathbf{v} = \rho_s\mathbf{v}_s + \rho_n\mathbf{v}_n$, $\mathbf{q} = \rho_s TS(\mathbf{v}_n - \mathbf{v}_s)$. The former is closely related to microscopic view and the second one to macroscopic experiments.

Here we present our recent numerical simulation in a 2D counterflow channel filled with turbulent superfluid helium in the TI status. The aim is to compare the obtained results to the ones achieved by means of the two-fluid model in the same conditions. This analysis would give more light to differences and analogies between these two models taking into account the recent experimental results obtained by Guo et al.[2] on the normal fluid profile.

1. Mongiovì, M.S. (1993). "Extended irreversible thermodynamics of liquid helium II", Phys. Rev. B **48**, 6276.

2. Guo, W.; Cahn, S.B.; Nikkel, J.A.; Vinen, W.F.; McKinsey, D.N. (2010). "Visualization Study of Counterflow in Superfluid 4He using Metastable Helium Molecules", Phys. Rev. Lett. **105**, 045301.

PS2.19 Counterflow channel: statistical studies on the normal component

L. Galantucci[a] and M. Sciacca[b]

[a]Dipartimento Ingegneria Strutturale, Politecnico di Milano, Italy

[b]Dipartimento SAF, Universitá di Palermo, Italy

A still open issue in superfluid helium II flows concerns the nature and the structure of the flows of the superfluid and normal fluid components in the presence of quantum vortices. The latter are responsible for the mutual friction interaction between the two phases which strongly modifies the vortex–free laminar flows of the two components. Experiments in counterflow channels employing metastable helium molecules[1] have concluded flat velocity profiles and theorized a turbulent structure for the normal fluid flow. In the present work, we focus our attention on: (i) the mesoscopic profile of the normal fluid velocity in different vorticity regimes (T I and T II), by the means of self-consistent two–dimensional numerical simulations of helium II channel counterflows; (ii) the statistical analysis of the structures of the superfluid and normal fluid velocity fields employing energy spectra, structure functions and PDFs. The ultimate aim is to give an important contribution for establishing whether the features of the T I and T II regimes determined in counterflow experiments are related to the conjectured turbulent transition of the normal fluid flow[2,3].

1. W. Guo, S. B. Cahn, J. A. Nikkel, W. F. Vinen, D. N. McKinsey, Phys. Rev. Lett. **105**, 045301 (2010).

2. D. J. Melotte, C. F. Barenghi, Phys. Rev. Lett. **80**, 4181 (1998) .

3. C. F. Barenghi, Physics **3**, 60 (2010).

PS2.20 Quantum Turbulence in a harmonically trapped Bose-Einstein Condensate: from Vortices to Granulation

R. F. Shiozaki, P. E. S. Tavares, G. D. Telles, E. A. L. Henn, and V. S. Bagnato

Instituto de Física de São Carlos, Universidade de São Paulo, C.P. 369, 13560-970 São Carlos, SP, Brazil

Quantum Turbulence (QT) is a tangled configuration of vortices in a superfluid such as a Bose-Einstein Condensate (BEC). We present experimental studies of a harmonically trapped BEC undergoing oscillatory excitations that can nucleate vortices, and generate QT [1]. First we analyze the vortex nucleation mechanism through ripples formation on the superfluid surface due to a counterflow motion between thermal and condensed components[2]. Then, considering the system's finite size characteristic, the transition from a non-turbulent vortex regime to a turbulent state is explained in terms of two excitation parameters: amplitude and duration[3]. As these parameters are further increased, a granular state resembling the Bose glass phase is reached[4].

1. Henn, E. A. L. *et al.* (2009). "Emergence of turbulence in an oscillating Bose-Einstein condensate". Phys. Rev. Lett. **103**, 045301.

2. Tavares, P. E. S. *et al.* (2013). "Out-of-phase oscillation between superfluid and thermal components for a trapped Bose condensate under oscillatory excitation". Laser Phys. Lett. **10**, 045501.

3. Shiozaki, R. F. *et al.* (2011). "Transition to quantum turbulence in finite-size superfluids". Laser Phys. Lett. **8**, 393–397.

4. Seman, J. A. *et al.* (2011). "Route to turbulence in a trapped Bose–Einstein condensate". Laser Phys. Lett. **8**, 691–696

PS2.21 Nonthermal Fixed Points and Superfluid Turbulence in an Ultracold Bose Gas

M. Karl, B. Nowak, and T. Gasenzer

Institute for Theoretical Physics, Heidelberg University, Germany

Turbulence appears in situations in which, *e.g.*, an energy flux goes from large to small scales where finally the energy is dissipated. As a result the distribution of occupation numbers of excitations follows a power law with a universal critical exponent. The situation can be described as a nonthermal fixed point of the dynamical equations. Single-particle momentum spectra for a dynamically evolving Bose gas are analysed using semi-classical simulations and quantum-field theoretic methods based on effective-action techniques. These give information about possible universal scaling behaviour. The connection of this scaling with the appearance of topological excitations such as solitons and vortices in one-component gases and domain walls and spin textures in multi-component systems is discussed. In addition their relation to those found in a field-theory approach to strong wave turbulence is discussed. In particular for three dimensional systems, the concept of nonthermal fixed points and its connection to transport processes in a turbulent system shows new aspects of the condensation dynamics out of equilibrium. The results open a view on a possibility to study nonthermal fixed points and superfluid turbulence in experiment without the necessity of detecting solitons and vortices in situ.

PS2.22 Zero-field vortex-induced Hall effect and polar Kerr effect in chiral p-wave superconductors near Kosterlitz-Thouless transition

C. K. Chung[a] and Y. Kato[b]

[a]Department of Physics, the University of Tokyo, Tokyo, Japan

[b]Department of Basic Science, the University of Tokyo, Tokyo, Japan

In this work, we investigate ac Hall and Ohmic conductivity induced by vortex dynamics in a chiral p-wave superconducting thin film near Kosterlitz-Thouless (KT) transition[1] without explicitly applying magnetic field. Dynamical theory developed by Ambegaokar, Halperin, Nelson, and Siggia[2] is generalized in such film. A matrix dielectric function describing vortex screening is obtained and related to the conductivity tensor. Polar Kerr effect due to the nonzero Hall conductivity is also studied. While the frequency and temperature dependence of Ohmic conductivity near KT transition in chiral p-wave context behave similarly to those of s-wave results, the Hall conductivity exhibits some novel features. Kerr angle is shown be proportional to the imaginary part of off-diagonal component of the dielectric function in certain parameter regime. As a result, Kerr angle measurement in experiment provides a probe of vortex dynamics described in this work. Contributions from bound pair as well as free vortex motion are demonstrated explicitly. In bound pair dynamics picture, we derive transverse and longitudinal response functions of a vortex-antivortex pair subjected to driving current, which contribute to many features in the conductivity tensor.[3]

1. J. M. Kosterlitz and D. J. Thouless, J. Phys. C **6**, 1181 (1973).
2. V. Ambegaokar, B. I. Halperin, D. R. Nelson, and E. D. Siggia, Phys. Rev. B **21**, 1806 (1980).
3. C. K. Chung and Y. Kato, arXiv:1303.3678 (2013).

PS2.23 Ac fluctuation conductivity in strongly fluctuating layered superconductors under magnetic field

B.D Tinh[a], D. P. Li[b], and B. Rosenstein[b]

[a]Department of Physics, Hanoi National University of Education, 136 Xuan Thuy Street, Cau Giay District, Hanoi, Vietnam

[b]Department of Physics, Peking University, Beijing 100871, China

The time-dependent Ginzburg-Landau approach is used to calculate ac fluctuation conductivity in layered type-II superconductor under magnetic field. Thermal fluctuations are assumed to be strong enough to melt the Abrikosov vortex lattice created by the magnetic field into a vibrating vortex liquid and marginalize the effects of the vortex pinning by inhomogeneities. In high-T_c materials large portion of the $H - T$ diagram belongs to this phase. Layered structure of the superconductor is accounted for by means of the Lawrence-Doniach model, while the nonlinear interaction term in dynamics is treated within self-consistent Gaussian approximation. We obtain expression summing all Landau levels are applicable essentially to whole liquid phase and are compared to experimental data on high-T_c superconductor $YBa_2Cu_3O_{7-\delta}$ and $Bi_2Sr_2CaCu_2O_{8+\delta}$. Above the crossover to the "normal phase" our results agree with previously obtained.

1. Tinh, B.D. (2013), Physica C 485, 10.

PS2.24 IV characteristics of array of antidots on superconducting Nb film

M. Kamran[b], M. Mumtaz[a], S. K. He[a], and X. G. Qiu[a]

[a]Beijing National laboratory of Condensed Matter physics, Institute of physics, Chinese Academy of Sciences P. O. Box 603, Beijing 100190, PRC

[b]Department of Physics, COMSATS Institute of Information Technology, Islamabad, Pakistan

We tuned the Shapiro steps in the I-V curves of superconducting thin film with square array of nano-engineered periodic anti-dots (holes) through applied temperatures; without applied rf frequencies. These Shapiro steps in the current-voltage characteristics of nano-engineered superconducting film investigated at temperature well below transition temperature. These I-V characteristic shows the sudden jumps (Shapiro steps) in the superconducting thin film with 2D array of antidots. These steps come out when the interstitial vortex lattice is formed and due to high vortex velocities, instability occurs and the system shows a step.

PS2.25 Magneto-resistance of a complex system i.e., Kagome array of antidots (holes)

M. Kamran[a], M. Mumtaz[c], S. K. He[b], S. P. Zhao[b], and X. G. Qiu[b]

[a]Department of Physics, COMSATS Institute of Information Technology, Islamabad, Pakistan

[b]Institute of Physics, CAS, and Beijing National Laboratory of Condensed matter Physics, Beijing, China

[c]Materials Research Laboratory, Department of Physics, FBAS, International Islamic University, Islamabad, Pakistan

In this work, we have investigated the magneto-resistance oscillations of one of the complex array i.e., kagome array of antidots (holes) on the superconducting Nb film. We observed the unusual magneto-resistance effect by sweeping the magnetic field during R-T magneto-resistance measurement. We tuned the magneto-resistance oscillations at different applied magnetic fields based on the R-H curves i.e., 0H, 1/2 H, and 1H. The 1/2H magneto-resistance curve has lower Tc as compared to 0H and even 1H, which unusual behavior in this kind of work. We have observed the unusual behavior in the R-H curve too i.e, the 1/2H dip in R-H curve. This behavior is due to the complex lattice of kagome array.

PS2.26 DC conductivity in a s-wave superconducting single vortex system

E. Arahata[a] and Y. Kato[b]

[a]Research Institute of Industry, The University of Tokyo

[b]Department of Basic Science, The University of Tokyo

One of the phenomena attracting attention is the dynamics of the vortex in type-II superconductors. Particularly, the Hall effect in the vortex state remains controversial. The quasiclassical Green function approach proved to be very useful for description of many properties both in superconducting single vortex systems. However, the quasiclassical equations, e.g. the Eilenberger equation[1], are unable to describe the flux flow Hall effect in the mixed state of superconductors. Recently, some works have a success to include the terms corresponding to the Hall effect in the quasiclassical equations[2]. However, there is no numerical calculation to clear the validity of these approaches with experimental parameters. We study this problem by using the quasiclassical equations including Hall effect terms. We solve the quasiclassical equations generalized by Kita in order to calculate dynamics of s-wave superconductor in the presence of moving single vortex. We calculate the dc linear response in a self-consistent way numerically in the sense that the gap equation (for the pair potential), the Dyson equation (for the impurity self-energy) and Maxwell equation (for electromagnetic fields) are satisfied up to the first order of vortex velocity. We discuss temperature and purity dependence of conductivities in details.

1. G. Eilenberger, Z. Phys. **214**, 195 (1968); A. I. Larkin and Y. N. Ovchinnikov, Sov. Phys. JETP **28**, 1200 (1969).
2. T. Kita, Phys. Rev. B **64**, 054503 (2001); N. B. Kopnin, J. Low Temp. Phys. **97**, 157 (1994).

PS2.27 Impurity effects in a vortex core in a chiral p-wave superconductor within the t-matrix approximation

N. Kurosawa[a], N. Hayashi[b], E. Arahata[c], and Y. Kato[a]

[a]Department of Basic Science, The University of Tokyo, Japan

[b]NanoSquare Research Center (N2RC), Osaka Prefecture University, Japan

[c]Institute of Industrial Science, The University of Tokyo, Japan

We study the effects of non-magnetic impurity scattering on the Andreev bound states (ABS) in an isolated vortex in a two-dimensional chiral p-wave superconductor numerically. We incorporate the impurity scattering effects into the quasiclassical Eilenberger formulation through the self-consistent t-matrix approximation[1]. Within this scheme, we calculate the local density of states (LDOS) around two types of vortices: "parallel" ("anti-parallel") vortex[2,3] where the phase winding of the pair-potential coming from vorticity and that coming from chirality have the same (opposite) sign.

When the scattering phase-shift δ_0 of each impurity is small, we find that impurities affect differently low energy quasiparticle spectrum around the two types of vortex in a way similar to that in the Born limit $(\delta_0 \to 0)^4$. For a larger $\delta_0(\leq \pi/2)$ however we find that ABS in the vortex is strongly suppressed by impurities for both types of vortex. We found that there are some correlations between the suppression of ABS near vortex cores and the low energy density of states due to impurity bands in the bulk.

1. E. V. Thuneberg, J. Kurkijärvi, D. Rainer, *Phys. Rev. B* **29**, 3913 (1984).
2. M. Matsumoto, M. Sigrist, *Physica C.* **281&282**, 973, (2000).
3. M. Sigrist, *Prog. Theor. Phys. Suppl.* **160**, 1, (2005).
4. Y. Kato, *J. Phys. Soc. Jpn.* **69**, 3378, (2000).

PS2.28 Decay of Quantum Turbulence Generated by Forced Flows of Superfluid ^{4}He

S. Babuin[b], E. Varga[a], and L. Skrbek[a]

[a]Faculty of Mathematics and Physics, Charles University, Ke Karlovu 3, 121 16 Prague, Czech Republic

[b]Institute of Physics ASCR, v.v.i., Na Slovance, 182 21 Prague, Czech Republic

We present an experimental study of the decay of quantum turbulence generated by a forced flow of superfluid ^{4}He down a 105 mm long, 7 mm wide square duct, with and without an obstructing grid. Steady state helium flows with velocity up to 1 m/s are produced by a low temperature bellows, and the turbulence decay originating from different initial intensities is studied in terms of the variation of density of quantized vortex lines as a function of time, deduced from the attenuation of second sound. The removable grid is located 10 mm upstream from the second sound sensors in the middle of the duct and has 0.5 mm mesh size and 0.1 mm tines. We have covered the temperature range $1.17 \leq T \leq 1.95$ K. Both steady state pipe turbulence and grid turbulence, when suddenly switched off, produce a decay of vortex line density across 4 orders of magnitude, lasting some 200 seconds, with a robust power law dependence of the form $t^{-3/2}$. The pipe turbulence decay is compared to a similar experiment where the normal component motion through the channel is prevented by use of superleak filters. The grid turbulence decay is compared to the bench-mark Oregon experiments where a grid was towed in stationary helium.[1] The measured data allow the computation of an effective kinematic viscosity associated with the coupled co-flow of normal and superfluid components of helium.

1. L. Skrbek, J. J. Niemela and R. J. Donnelly, Phys. Rev. Lett. **85**, 2973 (2000)

PS2.29 Dynamics of Solid Deuterium Particles in Quantum Turbulence Generated in Thermal Counterflow

D. Duda, M. La Mantia, M. Rotter, and L. Skrbek

Faculty of Mathematics and Physics, Charles University, Ke Karlovu 3, 121 16 Prague, Czech Republic

Quantum turbulence in thermal counterflow of superfluid ^{4}He is investigated by visualization at length scales $\ell_{\rm exp}$ ranging about two orders of magnitude across the mean distance ℓ between quantized vortices. The Lagrangian dynamics of solid deuterium particles of size $d \approx \ell/10$ is studied by using the particle image velocimetry and particle tracking velocimetry techniques. It is shown that the normalized probability distributions of the particle velocity and acceleration in the direction perpendicular to the counterflow velocity change from the power-law shapes typical of quantum turbulence, at $\ell_{\rm exp} < \ell$, to forms similar to those obtained for classical turbulent flows, at $\ell_{\rm exp} \approx \ell$.[1,2] Additionally, preliminary results on the dynamics of particles in thermal counterflow past a circular cylinder are discussed, focusing on the occurrence of macroscopic vortical structures in quantum turbulence and on the thermal counterflow generated by a heated cylinder.

We acknowledge the support of GAČR P203/11/0442.

1. M. La Mantia, T. V. Chagovets, M. Rotter, and L. Skrbek, Rev. Sci. Instrum. **83**, 055109 (2012)
2. M. La Mantia, D. Duda, M. Rotter, and L. Skrbek, J. Fluid Mech. **717**, R9 (2013)

PS2.30 Parallel Plates for Surface Magnetization Measurements of Superfluid ^{3}He

K. Akiyama, M. Wasai, M. Mashino, T. Nakao, R. Nomura, and Y. Okuda

Department of Physics, Tokyo Institute of Technology, Japan

We have carried out a series of measurements on the transverse acoustic impedance (Z)[1] of the superfluid ^{3}He and confirmed the existence of the surface Andreev bound states (SABS) inside the superfluid energy gap experimentally. We also have found a broadening of the SABS band and an extra low energy peak in Z as we increased the specularity towards the specular limit. Recently, it was claimed theoretically that the SABS of the superfluid ^{3}He B phase are Majorana fermions and the growth of the new peak is a strong indication of the Majorana cone at the specular limit[2,3].

To confirm the Majorana property further, we are planning to study the anisotropy in magnetic susceptibility of the SABS with respect to the external field which comes from the Majonara nature by NMR measurement. Since the SABS is confined to narrow region within some coherence lengths (ξ_0) from the wall, we have to increase the surface area to obtain enough surface signals over a bulk liquid one.

We invented a clever method and succeeded in fabrication of 150 parallel plates with 2.5-μm slabs[4]. We stretched sheets tight to keep sheet gaps and stacked them in layers to gain higher homogeneity of the slab thickness. Our average sheet gap was 2.50 ± 0.02 μm and the gap distribution was narrower than previously used ones.

1. Y. Okuda and R. Nomura, J. Phys.: Condens. Matter, **24**, (2012) 343201.
2. S. Murakawa et al., Phys. Rev. Lett. **103**, (2009) 155301.
3. S. Murakawa et al., J. Phys. Soc. Jpn. **80**, (2011) 013602.
4. K. Akiyama et al., J. Phys. Soc. Jpn. Suppl. in press.

PS2.31 Modal Decomposition in Goalpost Micro/nano Electro-mechanical Devices

E. Collin, M. Defoort, K. J. Lulla, C. Blanc, J. Guidi, S. Dufresnes, O. Bourgeois, and H. Godfrin

Institut Néel
CNRS et Université Joseph Fourier,
BP 166, 38042 Grenoble Cedex 9, France

We have studied the three firsts symmetric out-of-plane flexural resonance modes of a goalpost silicon micro-mechanical device. The fabrication process and first flexural mode have been described in Ref. [1]. Measurements have been performed at 4.2 K in vacuum, demonstrating high Qs and good linear properties. Numerical simulations have been realized to fit the resonance frequencies and produce the mode shapes. These mode shapes are complex, since they involve distortions of two coupled orthogonal bars. Nonetheless, analytic expressions have been developed to reproduce these numerical results, with no free parameters. Owing to their generality they are extremely helpful, in particular to identify the parameters which may limit the performances of the device. The overall agreement is very good, and has been verified on our nano-mechanical version of the device.

[1] E. Collin et al. *J. of Low Temp. Phys.* **150**, p. 739 (2008).

PS2.32 SRD1000 and CMN1000 sensors for precision thermometry below 8 K

W.A. Bosch[a] and R. Jochemsen[b]

[a]HDL, P.O. Box 691, 2300 AR Leiden, The Netherlands

[b]Kamerlingh Onnes Laboratory, LION, Leiden University, P.O. Box 9504, 2300 RA Leiden, The Netherlands

The SRD1000 superconductive reference device supports precision thermometry along the PLTS-2000 and ITS-90 by offering up to 13 calibrated reference points between about 15 mK and 8 K. A CMN1000 magnetic susceptibility thermometer supports continuous thermometry alongside the SRD1000 in the range from < 10 mK to 2 K. We report on recent developments to improve the quality of the SRD1000 reference points, and of the sensitivity, reproducibility and response time of the CMN1000 thermometer.

PS2.33 **Quantum Information Processing with Magnetically Trapped BECs in Cavity QEDs**

A. Abdelrahman and T. Byrnes

National Institute of Informatics 2-1-2 Hitotsubashi, Chiyoda-ku, Tokyo 101-8430

We propose in a new type of architecture for quantum information processing that based on the interaction of magnetically trapped ultracold quantum degenerate gases, such as atomic Bose-Einstein condensates (BECs), with external optical fields. Ultracold quantum gases are an interesting alternative as a realization of quantum memory, where a macroscopic number of atoms store quantum information. It has been shown recently that such systems can be used as effective qubits, and can be directly used to store and manipulate information [1,2]. In our work we use permanent magnetic traps to trap the atoms, which has the advantage of negligible technical noise, and thus decoherence, in comparison to more conventional current-carrying-wire based methods[3]. Several such nodes can be designed on the same device, realizing an array of trapped BECs. In order to communicate between various nodes, silica based waveguides are coupled to the atoms, by the use of microcavities centered around the magnetic traps. The proposed design allows the delivery of the optical fields (control/probe) to the trapped atoms through fabricated silica waveguides coupled to micro-cavities. Entanglement can be initiated between several cavities whenever an optical quantum bus is established on-demand by laser pulses between nodes as desired. We give a detailed derivation of the entanglement generation scheme and estimate the necessary experimental conditions for a working device.

1. T. Byrnes *et* al., Phys. Rev. A **85** , 040306(R) (2012). 2. A. Pyrkov, T. Byrnes, arXiv:1305.2479 (2013). 3. A. Abdelrahman *et* al.,Phys. Rev. A **82**, 012320 (2010).

PS2.34 **Vacuum measurements of a novel micro-resonator based on tin whiskers performed at mK temperatures**

M. Človečko[a], E. Gažo[a], S. Longauer[b], E. Múdra[b], P. Skyba[a], F. Vavrek[a], and M. Vojtko[b]

[a]Centre of Low Temperature Physics, Institute of Experimental Physics, Slovak Academy of Sciences, Watsonova 47, 040 01 Košice, Slovakia

[b]Department of Materials Science, Faculty of Metallurgy, Technical University of Košice, Park Komenského 11, 043 85 Košice, Slovakia

The spatial dimensions of traditional mechanical resonators used in the research of superfluid ^{3}He-B (e.g. vibrating wires/grids, quartz tuning forks, etc.) are usually much larger than the coherent length ξ, and this leads to a suppression of the energy gap near the surface of such resonators. As a consequence, the value of critical velocity v_c is lowered to 1/3 of the theoretical value for the Landau critical velocity v_L. Due to the excitations trapped near the resonator surface, the sensitivity of these devices is severely affected at ultra low temperatures, where the density of the volume excitations exponentially falls down. In order to increase resonators sensitivity at ultra low temperatures, one have to shorten their geometrical characteristics. There are several technological methods available to manufacture mechanical nano-resonators, however their quality factors Q is usually lower than those of classical mechanical resonators. We present a method of preparation and preliminary vacuum measurements conducted at $\sim 20\,$mK of a new type of micro-resonator based on tin-whiskers. Tin whiskers have $\sim 1\ \mu$m radius and their length can be $\sim 1 - 2$ mm. As added benefit, the tin whiskers are monocrystalline metal fibers with relatively smooth surface and being superconducting at low temperatures one may expect their high Q-factors.

PS2.35 Characterisation of a New Graphite Substrate for Measurements of Adsorbed Gases

F. Arnold[a], K. Kent[a], C.A. Howard[b], B. Yager[a], J. Nyéki[a], B. Cowan[a], and J. Saunders[a]

[a]Department of Physics, Royal Holloway University of London, Egham, TW20 0EX, United Kingdom

[b]London Centre for Nanotechnology, UCL, 17-19 Gordon Street, London, WC1H 0AH, United Kingdom

New graphitic substrates for the study of 2D adsorbed systems have been developed, offering superior properties to those presently available. The material is based around a natural graphite, intercalated to form a potassium ammonia intercalation compound, and exfoliated. The exfoliation process has been studied systematically and is carefully controlled. By exfoliating and recompressing graphite we form networks of mesoscopic graphite platelets with average sizes of 50 to 150 nm. Chemical analysis of our substrates shows fewer magnetic impurities than grafoil GTA, and no residue from the intercalation process.

Rocking curves performed on the 002 x-ray diffraction line are used to estimate the mosaic spread of samples, and line broadening in the 110 diffraction lines is used to infer in plane crystallite size. Thermodynamic analysis of nitrogen adsorption isotherms at 74 K is used to derive adsorption potential distributions which are related to surface quality.

We also present electrical transport and magnetisation measurements on exfoliated graphite in the temperature range of 1.8 to 300 K and magnetic fields up to 9 T. A strong dependence of the in-plane resistivity and magnetoresistance on the degree of exfoliation and mean platelet size is observed. The influence of exfoliation on the band structure was studied by means of de Haas-van Alphen and Hall-effect measurements.

PS2.36 A ^{3}He-^{4}He Dilution Refrigerator for Microgravity Experiments on a Small Jet Plane

T. Takahashi, H. Ohuchi, R. Nomura, and Y. Okuda

Department of Physics, Tokyo Institute of Technology, Japan

Ultra-low temperature experiments under zero gravity condition have drawn attentions[1] but not many experiments have been carried out due to the experimental difficulties[2]. Dilution refrigerators, a common device to get ultra-low temperatures, usually require the gravity for the continuous operation but special care have to be paid for the use in zero gravity. We developed a dilution refrigerator for microgravity experiments of ^{4}He crystal produced by a jet plane's parabolic flight. The jet plane was so small that the cryostat has to clear some restrictions such as experimental space, available electric power and total weight of the experimental system including refrigerators, vacuum pumps, measuring instruments and so on. The cryostat consisted of a dilution refrigerator and a GM refrigerator and was made to be compact and meet these restrictions. The dilution refrigerator unit was ordinary one and was not specially designed for the microgravity. The jet plane provides the microgravity for 20 s and we expected that it should work in this short period. We carried out the performance test of the dilution refrigerator under the microgravity environment this March to find it keeping its lowest temperature of 150 mK through the parabolic flight.

1. T. Takahashi, M. Suzuki, R. Nomura and Y. Okuda, "Development of a ^{3}He refrigerator for possible experiments of solid ^{4}He on a small jet plane" J. Low Temp. Phys. 162, 733 (2011).

2. T. Takahashi, R. Nomura, and Y. Okuda, "^{4}He Crystals in Superfluid under Zero Gravity" Phys. Rev. E 85, 030601(R) (2012).

PS2.37 A Method for Driving an Oscillator at a Quasi-Uniform Velocity

D. E. Zmeev

Department of Physics, Lancaster University, Lancaster, UK

Homogeneous and isotropic turbulence in superfluids in the low-temperature limit is extremely difficult to produce. One of the ways would be pulling a grid at a uniform velocity through the superfluid contained in a channel. The arising problem in this case is that the actuators pulling a grid at low temperature must be frictionless, so as to not cause excess heating. Hence, oscillations occur during the motion of an actuator, which undermine the uniformity of the velocity[1,2].

In this work we describe an electromagnetically driven "floppy grid" device similar to that described in Ref. 2 and a method for driving it at a quasi-uniform velocity, so that almost no oscillations occur during its motion and after reaching its destination. The method consists in profiling the driving force in such a way that the solution of the equation of motion of the actuator does not contain oscillatory motion. The parameters responsible for the form of the time dependence of the driving force are the effective resonant frequency and the effective damping parameter in the equation of motion of a simple harmonic oscillator with damping. Our method can result in motion of the grid in superfluid ^{4}He inside a channel over the distance of 4.3 cm at 10 cm/s with oscillations of less than 50 μm in amplitude (or less than 1 mm/s in terms of velocity).

1. G.G. Ihas, G. Labbe, S.C. Liu, and K.J. Thompson, J. Low Temp. Phys. **150**, 384 (2008).
2. D.I. Bradley, M. Človečko, M.J. Fear, S.N. Fisher, A.M. Guénault, R.P. Haley, C.R. Lawson, G.R. Pickett, R. Schanen, V. Tsepelin, and P. Williams, J. Low Temp. Phys. **165**, 114 (2011).

PS2.38 Development of Fiber-Optic Probe Hydrophone for Cryogenic Liquid

K. Obara, H. Ohmura, C. Kato, H. Yano, O. Ishikawa, and T. Hata

Department of Physics, Osaka City University, Japan

A calibrated, high-speed and local density/pressure probe can extend our physical view of nonlinear phenomena of liquid helium such as a flow-turbulence and an acoustic-turbulence[1]. A fiber-optic probe hydrophone (FOPH)[2] system can be the one, if it is applied in liquid helium. Our aim is to optimize FOPH for a cryogenic use. Here, the measurement principle of FOPH is based on the law of the classical optics called Fresnel reflection loss, which describes the light reflection at the interface between the two medium by which refractive indices differ. If the optical fiber is immersed in liquid helium, the reflection takes place at the end-face of the optical fiber, whose reflectivity is described as $[(n_f - n)/(n_f + n)]^2$. Here, $n_f = 1.4583$ and n are the refraction index of the fiber-core and liquid helium, respectively. Since the refraction index is the function of the density, one can obtain the pressure by measuring the reflectivity. The advantage of using FOPH is that its sensitivity does not show any frequency dependencies, up to GHz range[2], so, it is possible to calibrate the absolute value of the time-varying density/pressure using the hydrostatic pressure. And, it acts as a local density/pressure probe because the spatial resolution of FOPH is identical to the mode field diameter of the optical fiber, which is 5.6 μm in our system. Up to now, we have succeeded in measuring the density of liquid helium at saturated vapor pressure from 1.4 K to 4.3K. We will report the technical details of FOPH and the results of the density measurement, and discuss the possibility of measuring the pressure fluctuation and other applications.

1. K. Obara, et. al., J. Phys. Conf. Ser., **400**, 012057 (2012).

2. J. Staudenraus and W. Eisenmenger, (1992). Ultrasonics, **31**, 267-273

PS2.39 A microKelvin cryogen-free platform

G. Batey[a], A. Casey[b], M.N. Cuthbert[a], A.J. Matthews[a], J. Saunders[b], and A. Shibahara[b]

[a]Oxford Instruments Omicron NanoScience, Tubney Woods, Abingdon, Oxfordshire, OX13 5QX, UK

[b]Department of Physics, Royal Holloway, University of London, Egham, Surrey, TW20 0EX, UK

Cryogen-free dilution refrigerators coupled with superconducting magnets[1] allow the possibility of extending the temperature range accessible using completely cryogen-free systems into the μK regime by adding an adiabatic demagnetisation[2] stage to the refrigerator.

Here we present results from a cryogen-free nuclear demagnetisation cryostat utilising $PrNi_5$ as the refrigerant. Initial tests have attained temperatures of below 700 μK, as measured with a current-sensing noise thermometer mounted on an experimental plate. We find a hold time in excess of 24 hours at temperatures below 1 mK is possible, corresponding to a residual heat-leak into the nuclear stage of $\sim$ 5 nW.

The system requires only a modest (6 T) magnet to provide the initial entropy reduction and could be retrofitted to existing systems, that are suitable to operate such magnets, with minimal effort.

1. Batey, G. *et al.* (2009). “Integration of superconducting magnets with cryogen-free dilution refrigerator systems”. Cryogenics **49** 727-734

2. Debye, P. (1926). “Einige Bemerkungen zur Magnetisierung bei tiefer Temperatur”. Ann. Phys. (Leipzig) **81** 1154-1160

PS2.40 A Flux Noise Thermometer Optimized for Use at Ultralow Temperatures

A. Fleischmann, A. Reiser, D. Rothfuß, and C. Enss

Kirchhoff-Institut für Physik, Universität Heidelberg, Im Neuenheimer Feld 227, D-69120 Heidelberg, Germany

The determination of the temperature below 1 mK is still a great experimental challenge. We have developed a SQUID-based flux noise thermometer and optimized this device for use at ultralow temperatures. As a noise source we have chosen a piece of cold-worked high purity copper with a resisitivity that corresponds to a bandwidth of the noise thermometer of about 100 Hz due to self shielding effects. The flux noise caused by the thermal motion of the electrons in the copper is picked up by a DC SQUID via a small superconducting flux transformer. In order to supress the amplifier noise we used two independent DC SQUIDs simultaniously and cross-correlated their outputs. In this way we obtained a reduction of the ampifier noise of more than one order of magnitude. This new technique covers almost five orders of magnitude in temperature including ultralow temperatures which were accessible only by Pt NMR so far. We present the experimental technique and show data obtain at the cold stage of nuclear demagnetisation cryostat between 45 μK and 0.8 K.

Invited Oral Presentations: Saturday August 3rd

P3.1 Elasticity, Plasticity and Defects in Helium Crystals

J. Beamish[a], A. Haziot[b], A. Fefferman[b], X. Rojas[b], F. Souris[b], H.J. Maris[c], and S. Balibar[b]

[a]Department of Physics, University of Alberta, Edmonton, Canada[b]Laboratoire de Physique Statistique, ENS and CNRS, Paris, France

[c]Department of Physics, Brown University, Providence RI, USA

The elastic properties of solid ^{4}He change dramatically at temperatures between 50 and 200 mK, the same range where torsional oscillator (TO) measurements showed unusual behavior. The two types of experiment have the same dependence on temperature, amplitude and ^{3}He concentration. It now seems clear that the TO anomalies reflect changes in the helium's shear modulus, rather than mass decoupling of a supersolid. The shear modulus changes are due to dislocations, which are mobile at high temperatures and can reduce the shear modulus by as much as 80%, a phenomenon we describe as "giant plasticity". Below 200 mK, they can be pinned by ^{3}He impurities, restoring the helium's intrinsic stiffness. By growing single crystals in an optical cell, we could study the behavior of dislocations in helium in great detail. We identified the dislocations' glide direction, confirmed that the dislocation damping at high temperature was due to phonon scattering ("fluttering"), used this dissipation to measure dislocation densities and lengths, and studied the interaction between dislocations and mobile ^{3}He impurities. Temperature, impurity concentration and crystal quality can be varied over wide ranges in solid helium. This makes it a unique model system for materials science, in which the defects responsible for elastic and plastic behavior can be studied in great detail.

O3.1 The Giant Plasticity of a Quantum Crystal

A. Haziot[a], X. Rojas[a], A.D. Fefferman[a], J.R. Beamish[b], and S. Balibar[a]

[a]Laboratoire de Physique Statistique, ENS, Paris, France

[b]University of Alberta, Edmonton, Canada

We have shown that the shear modulus of ^{4}He single crystals is highly reduced in one particular direction if their dislocations are free to move. This "Giant Plasticity" occurs at low enough temperature where thermal phonons disappear and probably down to absolute zero if ^{3}He impurities are suppressed. By studying single crystals with various orientations, we have identified the gliding planes of the dislocations: it is the basal plane of the hcp structure. We found no dissipation in the plasticity region and a linear elastic behavior for single crystals down to 10 mK and nanobar stresses. This suggests that dislocations are strings moving freely with no measurable Peierls barriers to overcome, as assumed in the Granato-Lücke theory. We have also demonstrated that the dissipation occurring at higher temperature is due to collisions with thermal phonons. It allowed us to measure dislocation densities (10^4 to 10^6 cm^{-2} depending on crystal quality) and lengths (50 to 200 μm) precisely and to show that these dislocations are grouped in sub-boundaries, consequently poorly connected. These results rule out most existing scenarios for a possible supersolidity of solid helium 4. A comparison with classical crystals is interesting.

O3.2 Pursuit of the Elusive Supersolid

X. Mi and J. D. Reppy

Laboratory of Atomic and Solid State Physics and the Cornell Center for Materials Research, Cornell University, Ithaca, New York 14853-2501

The excitement following the initial report of supersolid behavior for ^{4}He embedded in porous Vycor glass has been tempered by the realization that many of the early supersolid observations were contaminated by effects arising from an anomaly in the elastic properties of solid ^{4}He. In an attempt to separate dynamic elastic effects from a true supersolid signal, we employed a torsional oscillator with two eigen frequencies to study the ^{4}He-Vycor system. We found that frequency dependent elastic signals can entirely account for the observed period shift signals. Although, we conclude that supersolid does not exist for the ^{4}He-Vycor case, the question of its presence in bulk samples remains open. In our current experiments we apply the two-frequency test to bulk samples of solid ^{4}He. Again we find a frequency dependent contribution arising from elastic effects. However, in some cases we also find a small frequency independent contribution, which may indicate the existence of a remnant supersolid phase. Given the history of this subject such results must be treated with caution.

1. X. Mi, and J. D. Reppy, Phys. Rev. lett. **108**, 225305 (2012).
2. E. Kim, and M.H.W. Chan, Nature **427**, 225 (2004).

O3.3 Microscopic Measurement of Flow of hcp Solid ^{4}He

Emil Polturak, Ethan Livne, and Anna Eyal

Technion - Israel Institute of Technology, Haifa, Israel

Although solid He does not exhibit supersolidity, there are nevertheless strong indications that individual crystallites can move in relation to the surrounding solid[1,2]. To try and observe such a flow of solid directly, we have constructed a sensitive “microphone” embedded in solid He contained inside a torsional oscillator. The microphone can detect vibrations down to the 10^{-11}m range, i.e. a few percent of a lattice constant. Our idea was that as the solid He flows past the microphone, the atomic corrugation would generate vibrations at a frequency $f = v/a$ where v is the flow speed and a is the lattice constant. For a speed of 10μm/sec, f falls in the 40-80 kHz range, depending on the direction of motion relative to the crystalline axes. The actual frequency was extracted from the time dependent signal using FFT. We indeed found that solid He can flow while maintaining its solid structure. From the data, we found that the flow is perpendicular to the c axis. In addition, our results reveal some microscopic aspects of the friction force between He crystals sliding past each other.

1. O. Pelleg, M. Shay, S. Lipson, E. Polturak, J. Bossy, J. C. Marmeggi, H. Kentaro, E. Farhi, and A. Stunault, Phys. Rev. B **73**, 024301 (2006).

2. A.Eyal, O. Pelleg, L. Embon, and E. Polturak, Phys. Rev. Lett. **105**, 025301 (2010).

O3.4 Flow-induced phase transitions in superfluid ^{3}He films[†]

A. B. Vorontsov[a] and J. A. Sauls[b]

[a]Department of Physics, Montana State University, USA
[b]Department of Physics and Astronomy, Northwestern University, USA

Confinement of superfluid ^{3}He to films with thicknesses of order $D \lesssim 15\,\xi_0$, where $\xi_0 = \hbar v_f / 2\pi k_B T_c \approx 200 - 800\,\text{Å}$, is the bulk coherence length, provides a unique environment to stabilize quantum phases that are not stable in bulk ^{3}He. Pair-breaking at interfaces, combined with correlations between the nine complex order parameter components, $A_{\alpha i}$, leads to suppression of certain components and enhancement of others. Transitions between different phases can be tuned via film thickness, pressure and temperature. In this presentation we describe a new degree of freedom - *superflow* - which in the context of confinement leads to several unique ordered phases. Superflow breaks time-reversal symmetry, axial rotation symmetry, and leads to new collective states. The quasiclassical equations of Eilenberger, Larkin and Ovchinnikov are solved self-consistently to identify the flow-stabilized phases of superfluid ^{3}He in cavities. Results for the inhomogeneous order parameter structures, their residual symmetry groups, and the film phase diagram are presented. The latter depends on the film thickness, D, flow velocity, v_s, and the surface boundary conditions. We present results based on microscopic models for specular, diffuse and retro reflection by the surface. The phase diagram is compared with existing experiments carried out in film and slab geometries. We also show the Fermionic spectrum of quasiparticles confined to the interface, and discuss the effects of flow-induced symmetry breaking, and of surface quality, on the Majorana spectrum.

[†]This research is supported by NSF Grants: DMR-0954342 and DMR-1106315.

O3.5 High speed imaging of generation and collapse of multielectron bubbles in liquid helium

V. Vadakkumbatt[a], E. M. Joseph[b], A. Pal[a], and A. Ghosh[b]

[a]Department of Physics, Indian Institute of Science, Bangalore, India
[b]Centre for Nano Science and Engineering, Indian Institute of Science, Bangalore, India

We study the generation and collapse of multielectron bubbles in liquid helium. We apply voltage pulses to a tungsten tip above the surface of the liquid, which results in the formation of mm sized dimples. Using high speed photography, we image the oscillation and disintegration of the dimples to bubbles of approximate sizes of few hundred microns. We believe these are multielectron bubbles (MEBs), each containing about 10^7 to 10^8 electrons. The MEBs were observed to travel downward for a short time till they disintegrated into smaller bubbles.

O3.6 Experiments to Study the Exotic Ions and the Effect of Light on Electron Bubbles in Superfluid Helium

W. Wei, Z.-L. Xie, G. M. Seidel, and H. J. Maris

Department of Physics, Brown University, Providence, Rhode Island 02912, USA

We present results of time-of-of-flight measurements of the mobility of negative ions (electron bubbles) in superfluid helium-4 at temperatures around 1 K. At saturated vapor pressure we introduce ions into the cell by means of a discharge in the vapor. For measurements at pressures up to 2 bars we produced ions by emission from sharp tips and from a Ni-63 beta source. With ions produced by a discharge we detect normal electron bubbles and the exotic ions seen previously by Ihas and Sanders, and by Eden and McClintock. We also see ions which have a continuous distribution of mobility. The continuous mobility distribution is very hard to understand based on the supposition that these ions are impurity ions or helium atom negative ions. We will discuss possible explanations of the continuous distribution.

When the ions come from the tip or the radioactive source the exotic ions and the continuous background are not seen. In previous experiments, the effect of light on the transport of negative helium ions has been reported as an increase in the current through the liquid when electron bubbles are injected and light is applied. The reason for the change in the current observed in these experiments was not established. In the present work, we are able to study this process in more detail because we can directly measure the change in the mobility of the electron bubbles after the light is applied. We will report new results obtained by this method.

Work supported in part by the National Science Foundation under Grant No. DMR 0965728.

P3.2 Exotic Quantum Phases of ^{3}He and ^{4}He in Two Dimensions

Hiroshi Fukuyama

Department of Physics, The University of Tokyo, Japan

The first three monolayers of ^{3}He and ^{4}He adsorbed on graphite are model systems for two-dimensional (2D) quantum liquids and solids which provide us new physics not usually seen in three dimensions (3D). I will discuss several examples including exotic ground states of the commensurate solids of both the isotopes in the second layer (C2 phase) by introducing recent experiments and theories. The second layer is perhaps the most intriguing system since there the kinetic energy, confining potential and particle correlations are comparable each other. The C2 phase is barely stabilized in the presence of a small potential corrugation at a relative density close to 4/7 with respective to the first layer. It has a significantly low density and hence the much higher delocalized nature than solid He in 3D. In the case of ^{3}He-C2 phase, the gapless quantum spin-liquid state of nuclear spins ($S = 1/2$) emerges below 1 mK unlike the antiferromagnetically ordered phase in bcc ^{3}He. The strong frustration caused by the triangular lattice structure and competing ring exchange interactions is responsible for the emergence of such an unusual state. Similar states are now discussed in electronic spin systems such as quasi-2D organic materials and transition metal oxides with frustrated lattices. An even more exotic quantum state is the supersolid phase expected in the C2 phase of ^{4}He. Torsional oscillator (TO) experiments using Grafoil substrate by three different groups show superfluid-like frequency shifts below 200 mK in this 2D bosonic solid. A new TO experiment using a better graphite substrate in terms of platelet size is now undergoing which would clarify if the tiny frequency shifts so far observed are of bulk superfluidity. Note that here He atoms localize choosing the particular density fraction and arrangement among others, which means that the C2 phase is a solid in a lattice space with spontaneous symmetry breaking.

O3.7 Confined ^{4}He Near T_λ: Scaling, Coupling and Proximity Effects

Francis M. Gasparini

University at Buffalo, The State University of New York, Buffalo, New York, 14260, USA

When ^{4}He is confined to a small uniform dimension L, its thermodynamic behavior near the superfluid transition is modified as the correlation length ξ becomes comparable to L. This can be described by crossover functions from three dimensions to a lower dimension. These functions depend only on the ratio ξ/L. This has been verified most extensively for the case where L represents the thickness of a film and the crossover dimension is two.[1] A more complex situation where two regions of ^{4}He are in contact, each characterized by a different L, allows one to study proximity effects and the coupling of one region with another through a 'weak link'. Recent measurements have shown that these effects are governed by the finite-size correlation length $\xi(t, L)$, where $t = |1 - T/T_\lambda|$; and, quite surprisingly, that the effects extend to distances over an order of magnitude larger than ξ.[2,3] This cannot be understood in terms of a mean field approach and must be due to the role of fluctuations at the superfluid transition. The long range of this effect is not understood at present. This behavior distinguishes ^{4}He from analogous behavior in the case of low temperature superconductors where such effects are on the scale of ξ/L.

1. F. M. Gasparini, M. O. Kimball, K. P. Mooney, and M. Diaz-Avila, Rev. Mod. Phys. **80**, 1009 (2008).
2. J. K. Perron, F. M. Gasparini, Phys. Rev. Lett. **109**, 035302, (2012).
3. J. K. Perron, M. O. Kimball, K. P. Mooney, and F. M. Gasparini, Phys. Rev. B **87**, 094507-16 (2013).

O3.8 Local Superfluidity at the Nanoscale

A. Del Maestro[a], G. Gervais[b], and B. Kulchytskyy[b]

[a]Department of Physics, University of Vermont, Burlington, VT 05405, USA
[b]Department of Physics, McGill University, Montreal, H3A 2T8, Canada

To understand how the enhancement of both thermal and quantum fluctuations affects superfluidity in low dimensional nanoscale constrictions, we have performed quantum Monte Carlo simulations measuring the superfluid response of helium-4 to the linear and rotational motion of the walls of a confining nanopore. Within the pores, the portion of the normal liquid dragged along with the boundaries is dependent on the type of motion and the resulting anisotropic superfluid density exhibits plateaus at low temperature. The origin of this saturation, which is not observed in bulk quantum fluids, is uncovered by computing the spatial distribution of superfluidity, with only the core of the nanopore exhibiting any evidence of phase coherence. We find that the superfluid core displays scaling behavior consistent with Luttinger liquid theory, thereby providing an experimental test for the emergence of a one dimensional quantum fluid.

O3.9 Superfluid flow and dissipation of ^{4}He confined in a well-controlled nanopore array

S. Murakawa[a], T. Tanaka[a], K. Osawa[a], A. Nakahara[b], K. Honda[b], Y. Shibayama[a], and K. Shirahama[a]

[a]Department of Physics, Keio University, Yokohama, Japan
[b]Department of Biological Science and Chemistry, Yamaguchi University, Yamaguchi, Japan

Superfluidity of liquid ^{4}He confined in nanopores with pore diameter of 3 nm is anomalously suppressed. The transition temperature approaches 0 K by pressurizing liquid, indicating a quantum phase transition between superfluid and nonsuperfluid states [1]. Since the suppression occurs at pore size much larger than the superfluid healing length $\xi \sim 0.3$nm, it opens possibility of developing novel superfluid weak links, i.e. superfluid Josephson junction working at wide temperature range, with nanopore fabrication technique. Here we report on measurements of superflow properties of ^{4}He in a regular array of nanopores made of porous alumina (PA). The pore size is controlled by Au film evaporated on and inside the nanopores. We employ the vibrating wire technique, in which the Au-evaporated PA is glued to a semicircular NbTi wire and is immersed in superfluid ^{4}He. Suppression of superfluid transition is successfully observed as an abrupt change in resonant frequency accompanying a dissipation peak. We find that, when the oscillation velocity of the wire increases, only the dissipation peak increases. The dissipation increases linearly with velocity at low temperature, while it saturates near the superfluid transition temperature inside the nanopores. We will discuss these behaviours in terms of phase slippages and turbulence by quantized vortices.

[1] K. Yamamoto *et al.*, Phys. Rev. Lett. **93**, 075302 (2004); K. Yamamoto *et al.*, Phys. Rev. Lett. **100**, 195301 (2008).

O3.10 Vortex-Antivortex unbinding in inhomogeneous atomic condensates

J. Tempere

TQC, Universiteit Antwerpen, Belgium

The effects of inhomogeneity and finite size on the binding energy of a vortex-antivortex pair, and on the entropy of the vortex state, are investigated in a two-dimensional atomic Bose-Einstein condensate (BEC) in a trap. The vortex-antivortex dissociation underpins the Kosterlitz-Thouless (KT) mechanism that explains the superfluid-normal transition in a two-dimensional BEC. The inhomogeneity, induced by the trapping potential, alters the usual heuristic Kosterlitz-Thouless argument, since both the binding energy and the entropy are different from the homogeneous, infinite case. Moreover, a real condensate rather than a quasicondensate is present in the 2D trapped system. The results from a full Gross-Pitaevskii calculation are compared with those of two simplified schemes: firstly a scheme where only the kinetic energy of the superfluid is taken into account, and secondly an even more simplified scheme where only the Magnus forces on point-like vortices are considered. In the trap, both the binding energy and the entropy decrease with respect to the homogeneous case, but since they are not decreased by the same amount, the Kosterlitz-Thouless temperature shifts. We compare our results to a recent observation of the vortex-antivortex dissociation temperature in atomic condensates. Finally, we investigate the influence of a disorder potential, introduced by laser speckle, on the KT mechanism.

O3.11 Dynamic structure function of a cold Fermi gas at unitarity

E. Krotscheck[a,b], T. Lichtenegger[a], G. Astrakharchik[c], and J. Boronat[c]

[a]Institute for Theoretical Physics, JKU Linz, Austria
[b]Department of Physics, University at Buffalo, SUNY Buffalo NY 14260
[c]Departament de Fisica i Enginyera Nuclear, Campus Nord B4-B5, Universitat Politécnia de Catalunya, E-08034 Barcelona, Spain

We present a theoretical study of the dynamic structure function of a resonantly interacting two-component Fermi gas at zero temperature. Our approach is based on dynamic many-body theory able to describe excitations in strongly correlated Fermi systems. The fixed-node diffusion Monte Carlo method is used to produce the ground-state correlation functions which are used as an input for the excitation theory. Our approach reproduces recent Bragg scattering data in both the density and the spin channel. In the BCS regime, the response is close to that of the ideal Fermi gas. On the BEC side, the Bose peak associated with the formation of dimers dominates the density channel of the dynamic response. Our results agree, in the spin-channel, quite well with recent measurements[1].

1. S. Hoinka, M. Lingham, M. Delehaye, and C. J. Vale:
Dynamic spin response of a strongly interacting Fermi gas, arXiv:1203.4657v1

O3.12 Excitations in Bose-Einstein condensates revisited

T. Kita

Department of Physics, Hokkaido University, Sapporo, Japan

We report new theoretical predictions for an interacting single-component Bose-Einstein condensate, which may change standard viewpoints on the system substantially.

Widely accepted results for the system may be summarized as follows. (i) Single-particle excitations can be described by the Bogoliubov mode with a linear dispersion and infinite lifetime at low energies; (ii) the Bogoliubov mode is also identical with the sound wave in the two-particle channel; (iii) it is the Nambu-Goldstone mode of broken $U(1)$ symmetry. On the other hand, there has been no reliable approximation schemes for the system that satisfies Goldstone's theorem and conservation laws simultaneously.

Recently, we have established a definite procedure to construct such approximations systematically to express the thermodynamic potential in a unique Luttinger-Ward form. According to this theory, each of the above statements should be modified as follows.[1] (i) The excitation in the single-particle channel is *not* the Bogoliubov mode *but* a bubbling mode with a finite lifetime even at low energies; (ii) the poles of the two-particle Green's function are *not* shared with those of the single-particle one, i.e., the two modes are different in character; (iii) the two distinct modes in the single- and two-particle Green's functions correspond to two different proofs of Goldstone's theorem by Goldstone *et al.* These qualitative changes originate from a new class of Feynman diagrams for the self-energy that has been overlooked so far, which is shown to modify the Lee-Huang-Yang correction for the ground-state energy.

[1]T. Kita, Phys. Rev. B **80**, 214502 (2009); *ibid.* **81**, 214513 (2010); J. Phys. Soc. Jpn. **80**, 084606 (2011).

Poster Presentations: Saturday August 3rd

PS3.1 Stacking fault energy and dislocation splitting in ^{4}He crystals

S. Balibar[a], J.R. Beamish[b], A.D. Fefferman[a], and A. Haziot[a]

[a]Laboratoire de Physique Statistique de l'ENS, associé au CNRS et aux Universités Denis Diderot et P.M Curie, 24 rue Lhomond 75231 Paris Cedex 05, France

[b]Department of Physics, University of Alberta, Edmonton, Alberta, Canada T6G 2E1

We present evidence for the existence of different staking faults in helium 4 crystals, whose energy can be lower than previously measured by Junes et al.[1]. Better agreement is found with different theoretical estimates of the stacking fault energy. Our observations support the prediction that edge dislocations are split into partials with a rather wide stacking fault between them. This splitting needs to be considered in future calculations of the binding energy of helium 3 atoms to edge dislocations, also for the understanding of the motion of dislocations including the recent discovery of their critical velocity[2,3,4].

This work is supported by grant ERC-AdG 247258 SUPERSOLID and by a grant from NSERC Canada.

[1] H.J. Junes et al., Low Temp. Phys. 153, 244 (2008).

[2]A. Haziot, X. Rojas, A. Fefferman, J. Beamish, and S. Balibar, Phys. Rev. Lett. 110, 035301 (2013).

[3] A. Haziot, A. Fefferman, J. Beamish, and S. Balibar, Phys. Rev. B 89, 060509(R) (2013).

[4] A. Haziot, A. Fefferman, J. Beamish, H.J. Maris, and S. Balibar, subm. to Phys. Rev. B (April 2013).

PS3.2 Evidence for a critical dislocation speed in helium-4 crystals

A. Haziot[a], A.D. Fefferman[a], J.R. Beamish[b], H.J. Maris[c], and S. Balibar[a]

[a]Laboratoire de Physique Statistique, ENS, Paris, France

[b]University of Alberta, Edmonton, Canada

[c]Brown University, Providence, USA

We have discovered two different regimes in the motion of dislocations in ^{4}He crystals when ^{3}He impurities are attached to them. At low driving strain ε and frequency ω , where the dislocation speed is less than 60 μm/s, dislocations and ^{3}He impurities apparently move together. At higher values of $\varepsilon\omega$, dislocations are pinned by ^{3}He impurities. This critical velocity is smaller but comparable to the velocity of free ^{3}He impurities in the bulk crystal lattice. We obtained this result by studying the dissipation of dislocation motion as a function of the frequency and amplitude of a driving strain applied to a crystal at low temperature. This resolves an apparent contradiction between experiments which indicated a thermally activated, frequency- dependent unbinding temperature and models in which the transition temperature was assumed to be independent of frequency. The impurity pinning mechanism for dislocations appears to be more complicated than previously assumed.

PS3.3 Vitrification of Liquid Inclusions in hcp ^{3}He-^{4}He Crystal: the Role of an Intermediate bcc Phase

N. P. Mikhin[a], A. P. Birchenko[a], A. S. Neoneta[a], E. Ya. Rudavskii[a], and V. G. Baidakov[b]

[a]B.Verkin Institute for Low Temperature Physics and Engineering of the National Academy of Sciences of Ukraine, Kharkov

[b]Institute of Thermal Physics, Ural Branch of the Russian Academy of Sciences, Yekaterinburg, Russia

Phase structure of rapidly quenched solid helium samples is studied by the NMR technique in dilute ^3He–^4He mixtures at $1.35 - 1.8$ K. The pulse NMR method is used to measure the spin-lattice T_1 and spin-spin T_2 relaxation times for all coexisting phases. It is found that just before vitrification which was detected previously[1], liquid inclusions in hcp matrix exhibit additional spin-lattice relaxation process. The new process is attributed to equilibrium bcc phase because the relaxation rate coincides with that of bcc solid, as well as the temperature range, wherein said contribution was detected, coincides with the temperature area of an equilibrium bcc phase on phase diagram. After finishing the of liquid inclusions vitrification, the contribution from the bcc phase is not detected. The role of highly dispersed bcc phase structure in the transition of liquid inclusions to the disordered state is discussed.

1. A.P.Birchenko, N.P.Mikhin, E.Ya.Rudavskii, and Ye.O.Vekhov, JLTP 169, 208 (2012).

PS3.4 The plastic flow of solid ^{4}He through a porous membrane

N. Mikhin, A. Lisunov, V. Maidanov, N. Neoneta, V. Rubanskyi, S. Rubets, E. Rudavskii, and V. Zhuchkov

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

The velocity of solid ^{4}He flowing through a porous membrane frozen into a crystal has been measured in the temperature interval 0.1 - 1.8 K using a flat capacitor consisting of a metalized plastic porous membrane and a bulk electrode. The clearance in the capacitor was filled with helium. The flow of helium through the membrane pores started as soon as d.c. voltage was applied to the capacitor plates. Above $T \sim 1$ K the velocity of the solid ^{4}He flow decreases with lowering temperature following the Arrhenius law. The activation energy of the process is close to that of vacancies. At low temperatures the velocity is only slightly dependent on temperature, which suggests a transition in ^{4}He from the classical thermally activated vacancy-related flow to the quantum plastic flow.

PS3.5 Nature of the Quantum Oscillation of Solid ^{4}He under DC Rotation

T. Tsuiki[a], D. Takahashi[b,c], S. Murakawa[a], K. Kono[c], and K. Shirahama[a]

[a]Department of Physics, Keio University, Yokohama 223-8522, Japan

[b]Division of General Education, Ashikaga Institute of Technology, Ashikaga 326-8558, Japan

[c]Low Temperature Phys. Lab., RIKEN, Wako-shi 351-0198, Japan

Recent our finding of quantum oscillation in solid ^{4}He under DC rotation, in which "Non-classical Rotational Inertia (NCRI)" oscillates as a function of inverse angular velocity Ω^{-1} can be possible evidence of supersolidity. Because it is genuine quantum phenomena in solid ^{4}He such as "de Haars-van Alphen" effect in fermionic matter. This rotating result is hard to explain by change in elasticity of solid. The cell used at the previous experiment contained not only annular Vycor but also unexpected small bulk space. We observed enhancement of NCRI and stabilizing of quantum oscillation when using solid made above 5.6 MPa. By contrast, NCRI reduces and the quantum oscillation vanishes at 2.8 MPa at which no solid forms in Vycor. We suppose that composite of bulk solid and solid in Vycor, both "super"solid, is a key role of the oscillation. This hypothesis, however, disagrees with a recent claim that no NCRI was observed in solid confined in Vycor[1]. Revealing the nature of quantum oscillation of solid ^{4}He, we prepare DC rotation experiment with new torsional oscillator containing annular Vycor which rule out bulk space.

1. D.Y.Kim and M.H.W.Chan, Phys. Rev. Lett. **109** 155301 (2012).

PS3.6 Quantum Vortex Physics in hcp solid ^{4}He

Minoru Kubota[a], Hiroaki Ueda[b], Masahiko Yagi[c], and Kris. Rogacki[d]

[a]Shibaura Institute of Technology, Tokyo, Japan

[b]Okinawa Institute of Science and Technology, Japan

[c]Institute for Solid State Physics, the University of Tokyo, Japan

[d]Institute of Low Temp. and Struct. Res., Pol. Acad. Sci., Wroclaw, Poland

The nature of solid ^{4}He has been questioned by recent reports by Xiao Mi and Reppy[1] as well as by Chan's group[2] that careful experiments reveal the absence of the supersolid behavior in the solid He in Vycor glass. We discuss that these observations can be explained by the characteristic length scales of the supersolidity below T_c as well as in the vortex fluid state below the onset temperature T_o of hcp He in comparison to the Vycor pore size. Furthermore we present new evidences supporting supersolid state below T_c as well as the vortex fluid state below T_o in terms of physics of quantized vortices. Some of the essential points of our discussion has been already published and summarized in [3]. The characteristic length scales were obtained by the absolute size evaluation of the supersolid mass both in the supersolid state and in the vortex fluid state. Further detailed discussion based on the physics of quantized vortices which explaines many of the observations will be given. Authors acknowledge supports from Gen Tatara(Riken), Masato Murakami(SIT), and encouragement by P.W. Anderson.

1.Xiao Mi and John D. Reppy, "Anomalous Behavior of Solid 4He in Porous Vycor Glass", PRL 108, 225305 (2012). 2. Duk Y. Kim and Moses H. W. Chan, "Absence of Supersolidity in Solid Helium in Porous Vycor Glass", PRL 109, 155301 (2012). 3. Kubota, M. (2012). "Quantized Vortex State in hcp Solid ^{4}He". J Low Temp Phys, 169, 228-247.

PS3.7 **Shear Modulus and Thermal Conductivity of Polycrystalline hcp ^{4}He at Low Temperatures**

M. Yu. Brazhnikov[a], Y. M. Mukharsky[b], D. E. Zmeev[a], A. A. Levchenko[c], and A. I. Golov[a]

[a]School of Physics and Astronomy, The University of Manchester, Manchester M13 9PL, UK

[b]CEA-Saclay/SPEC, Gif-sur-Yvette – Cedex, 91191 France

[c]Institute of Solid State Physics, Russian Academy of Sciences, Chernogolovka 142432, Russia

We have built a high-quality ($Q = 5 \times 10^6$) torsional oscillator with a hollow torsional rod of 1.1 mm i.d. Results of investigations of the rigidity and thermal conductivity of polycrystalline samples of hcp ^{4}He, grown inside the torsional rod, will be presented.

PS3.8 **Response of a Mechanical Oscillator in Solid ^{4}He**

S. Ahlstrom[a], D. I. Bradley[a], M. Človečko[b], S.N. Fisher[a], E. Guise[a], A. M. Guénault[a], R. P. Haley[a], O. Kolosov[a], M. Kumar[a], P. V. E McClintock[a], G. R. Pickett[a], M. Poole[a], V. Tsepelin[a], and A. Woods[a]

[a]Department of Physics, Lancaster University, Lancaster, LA1 4YB, UK

[b]Present address: Slovak Academy of Sciences, Kosice, Slovakia

We present the first measurements of the response of a mechanical oscillator in solid ^{4}He. We use a lithium niobate tuning fork operating in its fundamental resonance mode at a frequency of around 30 kHz. Measurements in solid ^{4}He were performed close to the melting pressure. The tuning fork resonance shows substantial frequency shifts on cooling from around 1.5 K to below 10 mK. The response shows an abrupt change at the bcc-hcp transition at around 1.46 K. At low temperatures, below around 100 mK, the resonance splits into several overlapping resonances.

PS3.9 **Plastic Properties of Solid ^{4}He Probed by a Moving Wire: Viscoelastic and Stochastic Behavior Under High Stress**

S. Ahlstrom[a], D. I. Bradley[a], M. Človečko[b], S.N. Fisher[a], E. Guise[a], A. M. Guénault[a], R. P. Haley[a], O. Kolosov[a], M. Kumar[a], P. V. E McClintock[a], G. R. Pickett[a], E. Polturak[c], M. Poole[a], I. Todoshchenko[d], V. Tsepelin[a], and A. Woods[a]

[a]Department of Physics, Lancaster University, Lancaster, LA1 4YB, UK

[b]Present address: Slovak Academy of Sciences, Kosice, Slovakia

[c]Faculty of Physics, Technion-Israel Institute of Technology, Israel

[d]Aalto University, Finland

We present the first measurements of a thin wire moving through solid ^{4}He. Measurements were made over a wide temperature range at pressures close to the melting curve. We describe the new experimental technique and present preliminary measurements at relatively high driving forces (stresses) and velocities (strain rates). The wire moves by plastic deformation of the surrounding solid facilitated by quantum tunneling of vacancies and the motion of defects. In the bcc phase we observe very pronounced viscoelastic effects with relaxation times spanning several orders of magnitude. In the hcp phase we observe stochastic step-like motion of the wire. During the step, the wire can move at extremely high velocities. On cooling, the wire ceases to move at a temperature of around 1 K. We are unable to detect any motion at lower temperatures, down to below 10 mK.

PS3.10 **Supersolidity Mimics Superfluidity in Other Scale**

N. V. Krainyukova

Institute for Low Temperature Physics and Engineering NASU, Kharkiv, Ukraine

This work is devoted to our new and wider insight into the problem of supersolidity. In contrast with many other studies where only a short temperature interval (mainly T<0.5 K) is considered we propose a different overview of the whole range of solid helium existence. Comparing temperature dependences of NCRI, heat capacity and shear modules we conclude that all unusual effects can be of the same nature and successfully explained within the suggested theory of rotational excitations in solid helium (first introduced at QFS'2010[1]) with smaller (at higher T), larger (at lower T) domains of correlated rotations and frozen approaching T=0. Shorter correlations (short-range order) could be inherent as well in superfluid helium that may explain the temperature dependence of viscosity. Because of negligible contribution of dislocations in the specific heat ($\sim 10^{-21}$ k_B at 0.1 K, k_B - Boltzmann constant)[2] and irrelevance to liquid helium we conclude that dislocations may not be responsible for similarities in temperature dependences of all mentioned properties.

1. N.V. Krainyukova, J. Low Temp. Phys. **162**, 441 (2011)

2. A. Granato, Phys. Rev. **111**, 740 (1958)

PS3.11 Rotational, Vibrational and Glassy States in Solid Helium with Impurities

N. V. Krainyukova

Institute for Low Temperature Physics and Engineering NASU, Kharkiv, Ukraine

In this work we successfully apply our theory of rotational excitations in solid helium to describe an unusual behaviour of the specific heat of solid helium[1], which increases at temperatures approaching T=0 and for higher impurity (^{3}He) concentrations. We show that three contributions: rotational, vibrational and glassy compete and perfectly describe experimental observations without any additional assumptions. The contribution of glassy states is largest for samples with lowest in energy rotational excitations that supports our idea concerning the reason for stiffening in helium at lowest temperatures when rotational excitations are frozen up.

1. X. Lin, A. C. Clark, Z. G. Cheng, M. H.W. Chan, Phys. Rev. Lett. **102**, 125302 (2009)

PS3.12 The distribution of dislocation lengths in ^{4}He crystals

A. D. Fefferman[a], F. Souris[a], A. Haziot[a], J. R. Beamish[b], and S. Balibar[a]

[a]Laboratoire de Physique Statistique de l'ENS, Paris, France

[b]Department of Physics, University of Alberta, Edmonton, Canada

The existence of mobile dislocations results in plasticity of crystals. The "giant plasticity" of ultra pure ^{4}He crystals at low temperature is a consequence of the free motion of their dislocations between the nodes in their network. By measuring the shear modulus as a function of the nano-strain applied to our crystals, we have demonstrated that there is not a single free length of dislocations between nodes in their network but a rather large distribution of these lengths, which we have measured. By including this distribution in an improved model of the dislocation motion, we obtain excellent agreement with all measurements of the shear modulus and the dissipation as a function of both temperature and the applied strain.

PS3.13 Disorder and melting in doped solid helium studied by dopant laser spectroscopy

P. Moroshkin[a,b], V. Lebedev[a], and A. Weis[a]

[a]Department of Physics, University of Fribourg, Switzerland

[b]Low Temperature Physics Laboratory, RIKEN, Japan

Optical spectra of foreign atoms and molecules embedded in liquid or solid helium provide information about the local properties of cryogemic fluid/solid quantum matrices. In particular, the embedded metal atoms reside in nanometer-sized cavities known as atomic bubbles and their optical properties are very sensitive to variations of the density and the anisotropic elasticity of the He matrix [1]. The dopants can thus be used as microscopic sensors for time-resolved studies of He solidification and melting.

We present an experimental study of laser-induced fluorescence spectra of Cs-doped solid ^{4}He, heated locally by intense nanosecond laser pulses. The observed spectra are compared with quantum fluid/solid bubble model predictions and with the results of line broadening theory for high density gas phase atomic collisions.

Our results indicate that the fast local heating of crystalline He produces a disordered solid with a large number of defects. The defects have a pronounced effect on the shift and broadening of the atomic bubble spectra that cannot be predicted by conventional atomic bubble models. At sufficiently high laser pulse energies we observe a transient local melting of the crystal that leads to a strongly inhomogeneous sample with embedded micro-bubbles of relatively hot pressurized He fluid. A further increase of the laser power induces a macroscopic melting of the sample.

1. P. Moroshkin, A. Hofer, A. Weis, Physics Reports **469**, 1 (2008).

PS3.14 Lattice Relaxation in Solid ^{4}He — Effect on Dynamics of ^{3}He Impurities

N. S. Sullivan[a], D. Candela[b], S. S. Kim[c], C. Huan[d], L. Yin[a], and J. S. Xia[a]

[a]Department of Physics, University of Florida, Gainesville,USA.

[b]Department of Physics, University of Massachusetts, Amherst,USA.

[c]Ècole Polytechnique Fèdèrale de Lausanne, Lausanne, Switzerland.

[d]Department of Physics, Georgia Institute of Technology, Atlanta, USA.

We review the effect of lattice relaxation that accompanies the quantum tunneling of ^{3}He impurities in solid ^{4}He on the nuclear spin-lattice relaxation of the ^{3}He impurities for very low impurity concentrations. As a result of the larger zero point motion of the ^{3}He impurity compared to the ^{4}He atoms, a significant lattice distortion accompanies the impurity as it moves through the lattice and the dynamics of the impurity depends on both the interaction energy between two ^{3}He atoms and on the relaxation of the lattice for the tuneling impurity. Using a phenomenologiocal model for the lattice relaxation we compare the observed nuclear spin-lattice relaxation rates observed at low temperatures with the dependence on temperature expected for a ^{4}He lattice relaxation comparable to that observed by Beamish *et al.*[1]

1. O. Syshchenko, O., Day, J. and Beamish, J. Phys. Rev. Lett. **104**,195301 (2009).

PS3.15 Specific Heat Measurement of the Gapless Spin Liquid State in 2D ^{3}He

M. Kamada[a], D. Sato[b], Y. Kubota[a], S. Nakamura[a], T. Matsui[a], and Hiroshi Fukuyama[a]

[a]Department of Physics, The University of Tokyo, Japan

[b]RIKEN, Wako, Japan

The second layer of ^{3}He adsorbed on a surface of graphite is known to form a low density commensurate (C2) phase with a triangular lattice structure sometimes called the 4/7 phase at low temperatures (T). Previous experiments[1,2] show that the ground state of this phase is a promising candidate for the gapless quantum spin liquid (QSL) without long range order and spin excitation gap. This is based mainly on the observed double peak structure of specific heat (C) with a seemingly $C \propto T$ behaviour and the continuous and gradual increase of magnetic susceptibility at low-T. To test this hypothesis, we are measuring C of the C2 phase adsorbed on graphite preplated with a bilayer of HD at T well below a typical strength of various multiple spin exchange interactions ($|J_P| \approx 100$ mK) among the nuclear spins ($I = 1/2$). Data so far obtained indicate that the $C \propto T$ dependence holds down to 0.4 mK below a broad single maximum around 5 mK. They are indicative of the formation of Spinon Fermi surface in the gapless QSL and the high sensitivity of $|J_P|$ to density in quantum solids. We are now extending the measurement down to 0.1 mK and preparing an NMR measurement of the spin-spin relaxation time (T_2) in order to obtain direct information on the spin dynamics of QSL which is usually difficult to acquire from electronic counterpart materials. Preliminary data show that T_2 gradually decreases around T corresponding to the broad C maximum and saturates at the lowest-T.

1. K. Ishida *et al.*, Phys. Rev. Lett. **79**, 3451 (1997).
2. R. Masutomi *et al.*, Phys. Rev. Lett. **92**, 025301 (2004).

PS3.16 ^{4}He crystals on an oscillating plate

T. Yoshida, A. Tachiki, N. Ishii, R. Nomura, and Y. Okuda

Department of physics, Tokyo Institute of Technology, Tokyo 152-8551, Japan

^{4}He crystals placed on a transversely oscillating plate was investigated visually in superfluid. The plate was glued on a piezo device which was driven in a shear mode electrically. The amplitude of the oscillation at low temperatures was about 0.7 μm by application of $\pm$150 V. Facets of a single ^{4}He crystal of 3 mm in diameter were destroyed by a single saw-tooth pulse of 1 ms duration at 0.4 K. In case of a larger crystal of 7.5 mm in diameter and 0.8 mm in height, only one side of the crystal was melted by application of 100 pulses with 10 ms intervals; crystal surface of the left hand side in view approached to the right hand side while the right hand side never moved. The crystal grew in the vertical direction and its height became about 1.4 mm during the pulses. The crystals were found to respond to the oscillation sensitively and the saw-tooth pulse induced a very anisotropic motion of the crystal surface. Inchworm drive is a well known method to drive an object on a plate utilizing the difference between the static and dynamic frictions. A possible application of this device for driving ^{4}He crystals in superfluid will be also discussed.

PS3.17 Search for Supersolidity in Monolayer ^{4}He on Graphite

Y. Kubota[a], R. Toda[b], M. Kamada[a], S. Nakamura[a], T. Matsui[a], and Hiroshi Fukuyama[a,b]

[a]Department of Physics, The University of Tokyo, Japan

[b]Cryogenic Research Center, The University of Tokyo, Japan

Recent heat capacity measurements for the second layer of ^{4}He adsorbed on ZYX graphite, an exfoliated graphite with much larger platelet size than Grafoil, clearly show the existence of a commensurate phase (C2) at a density $\rho_{C2} = 19.7$ nm^{-2} in between a low density liquid phase and a high density incommensurate phase [1]. The C2 phase is the lowest density quantum solid ever found with substantially fast exchanges of atoms and vacancies. Therefore, it is a hopeful candidate for the novel supersolid phase where crystalline order coexists with superfluidity. Previous torsional oscillator measurements of the second layer of ^{4}He by three different groups using Grafoil show frequency shifts below 300 mK at densities near ρ_{C2} suggesting unusual superfluidity [2]. However, the observed reentrant density variations of superfluid response are rather different each other, and the shifts are too small to convince the supersolidity. This is presumably because of large uncertainties in their density scales and poor connectivity of platelet boundaries in Grafoil. Here, we report details of experimental setup and preliminary results of our new torsional oscillator measurement down to 10 mK on the second layer of ^{4}He. The oscillator made of coin silver containing ZYX substrate with a surface area of 4.6 m^2 has $f = 786.819$ Hz and $Q = 1.1 \times 10^5$.

[1] S. Nakamura, *et al.*, to be published.
[2] P. A. Crowell and J. D. Reppy, Phys. Rev. B **53**, 2701 (1996); Y. Shibayama *et al.*, J. Phys. Conf. Ser. **150**, 032096 (2009); J. Saunders, private communication.

PS3.18 Falling and collision of ^{4}He crystals in superfluid

R. Nomura, T. Yoshida, A. Tachiki, T. Takahashi, H. Ohuchi, and Y. Okuda

Department of physics, Tokyo Institute of Technology, Tokyo 152-8551, Japan

Detailed crystal shape of ^{4}He during a free falling was investigated in superfluid by a high speed video camera. A ^{4}He crystal was nucleated by a ultrasound transducer on the top of a sample cell and the crystal fell in the superfluid and collided with the bottom. During the falling, upper surface of the crystal became rough and lower surface became facetted. This is possibly caused by the superflow around the crystal which induced the melting in the upper surface and the crystallization in the lower surface. When it collided with the bottom, pulse-like wave traveled around the surface from the contact point and the crystal transformed itself quickly to adjust to a new boundary condition. We also investigated how crystals fell when a small needle was placed in the falling path. The crystal surface was drawn and stretched by the needle. This strange interaction between the crystal and the needle is probably induced by the superflow around the crystal but is not well understood at present. Collisions of two ^{4}He crystals were also observed and the smaller crystal was melted and taken into the larger one after the collision.

PS3.19 Gravity-Free ^{4}He Crystals in Superfluid at 150 mK

T. Takahashi, H. Ohuchi, R. Nomura, and Y. Okuda

Department of Physics, Tokyo Institute of Technology, Japan

We have studied ^{4}He crystals in superfluid under microgravity environment produced by a jet plane's parabolic flight. We succeeded in developing a dilution refrigerator for the jet plane experiments and observed the crystals at 150 mK which is much lower than in the previous studies[1,2]. The equilibrium shape of a ^{4}He crystal determined predominantly by the surface free energy under microgravity and its reaction to acoustic waves were observed. Though only the rough surfaces and the *c* facet were identified on the equilibrium crystal in gravity, the *a* and *s* facets newly emerged on the equilibrium crystal under microgravity but no other facets appeared. The crystal stuck to the wall of sample cell during the microgravity period and its shape did not greatly change. This is because the crystal surface was pinned to the side wall of the cell keeping the contact angle between the crystal and the wall constant. The crystal was not able to escape from this metastable configuration. However, when we applied acoustic waves to the *c* facet of the crystal, the *c* facet grew quickly and the crystal was largely deformed. Thereafter, the deformed crystal relaxed to a different shape to adjust to a new boundary condition: the crystal had a contact only with the bottom wall and the *c,a* and *s* facets rearranged their size and shape. Acoustic waves were found to be very effective to manipulate the crystal to study its dynamics under microgravity.

1. T. Takahashi, H. Ohuchi, R. Nomura, and Y. Okuda, "Ripening of Splashed ^{4}He Crystals by Acoustic Waves with and without Gravity" New J. Phys. 14, 123023 (2012).

2. T. Takahashi, R. Nomura, and Y. Okuda, "^{4}He Crystals in Superfluid under Zero Gravity" Phys. Rev. E 85, 030601(R) (2012).

PS3.20 Frequency change of torsional oscillator induced by solid ^{4}He in torsion rod

Y. Aoki[a], I. Iwasa[b], T. Miura[c], A. Yamaguchi[d], S. Murakawa[e], and Y. Okuda[c]

[a]Department of Materials Science and Engineering, Tokyo Institute of Technology, Japan

[b]Department of Mathematics and Physics, Kanagawa University, Japan

[c]Department of Physics, Tokyo Institute of Technology, Japan

[d]Department of Material Science, University of Hyogo, Japan

[e]Department of Physics, Keio University, Japan

The contribution of the solid ^{4}He in the torsion rod to the resonance frequency of the torsional oscillator(TO) was investigated. The origin of the frequency increase of TO below ∼0.2 K with solid ^{4}He is still unclear. In the conventional TO's setup, ^{4}He is supplied to the oscillator's body through a hole located at the center of the torsion rod. In the previous studies, the frequency increase has been regarded to be caused by the decrease of the rotational momentum inertia (I) of solid ^{4}He in the torsion body. However, the spring constant (K) of TO may be affected by the solid in the torsion rod [1]. To measure the contribution from the solid in the torsion rod, we constructed two different TOs, one is the cylindrical conventional TO which includes the solid in the body and in the torsion rod, and another one includes the solid only in the torsion rod. By comparing the results from the two setups, the contribution of the solid in the torsion rod to the frequency change was estimated.

The experiment was performed in ISSP as joint research.

[1]. J. Beamish *et al.*, Phys. Rev. B, 85, 180501 (2012).

PS3.21 Power law behavior of quantum crystallization of ^{4}He in aerogel

R. Isozaki, H. Matsuda, A. Ochi, R. Nomura, and Y. Okuda

Department of physics, Tokyo Institute of Technology, Tokyo 152-8551, Japan

Two different crystallization processes of ^{4}He in aerogels, observed as creep at high temperatures and avalanche at low temperatures[1], have been clarified from both the crystallization rate[2] and nucleation probability measurements[3] that the former is via the thermal activation and the latter is via the macroscopic quantum tunneling. In the quantum tunneling regime, a power law behavior was observed in the avalanche size distribution[2]. This is the first demonstration of the self-organized criticality at low temperatures where the quantum nature dominates the dynamical properties of the system. The large-scale cut-off of the power law distribution decreased toward the transition temperature which is probably caused by a dissipation effect on the quantum tunneling. We further investigated the intervals and distances of two successive avalanches and found that they also follow power law distributions. The distance distribution deviated from the power law in the small and large scales; deviation in the small scale is the finite size effect of the avalanches, while the deviation in the large scale is the effect of aerogel size.

1. R. Nomura, A. Osawa, T. Mimori, K. Ueno, H. Kato and Y. Okuda, "Competition between thermal fluctuations and disorder in the crystallization of ^{4}He in aerogel" Phys. Rev. Lett. 101, 175703 (2008).

2. R. Nomura, H. Matsuda, R. Masumoto, K. Ueno and Y. Okuda, "Macroscopic Quantum Tunneling and Avalanche Size Distribution of ^{4}He Crystallization in Aerogel" J. Phys. Soc. Jpn. 80, 123601 (2011).

3. H. Matsuda, A. Ochi, R. Isozaki, R. Masumoto, R. Nomura and Y. Okuda, "Thermal and Quantum Nucleation of ^{4}He Crystals in Aerogel" Phys. Rev. E 87, 030401(R) (2013).

PS3.22 Fluctuating surfaces of growing ^{4}He crystals in aerogel

H. Matsuda, A. Ochi, R. Isozaki, R. Nomura, and Y. Okuda

Department of physics, Tokyo Institute of Technology, Tokyo 152-8551, Japan

Crystallization of ^{4}He in aerogel was shown to exhibit a dynamical transition in the growth mode: crystals grow via creep at high temperatures and via avalanche at low temperatures. It was also found from both crystallization rate and nucleation probability measurement that crystals grow via thermal activation in the high-temperature creep region and via macroscopic quantum tunneling in the low-temperature avalanche region[1]. In the growth regime via quantum tunneling avalanche size distribution follows a power low and indicates that the system is in a self-organized critical state (SOC)[2]. It is interesting that ^{4}He in aerogel can provide a good system to study the fundamental physics of crystal growth. In this report we focus on the shape of the growing interface in the high-temperature creep region and attempted to analyze the roughness of interfaces. The growth of rough interfaces is commonly observed in nature and the roughness is known to often follow a scaling low; roughness usually increases with time and saturates in the later stage. We measured the width $w(t)$ defined as the standard deviation of the interface height as a function of time t. It was found that $w(t)$ in 98 percent porosity aerogel nitially increased with t and decreased after a particular time in the later stage. The abrupt reduction of roughness in the end of crystallization is unusual. The possible interpretation is under consideration.

1. H. Matsuda, A. Ochi, R. Isozaki, R. Masumoto, R. Nomura and Y. Okuda, Thermal and Quantum Nucleation of ^{4}He Crystals in Aerogel, Phys. Rev. E **87**, 030401(R) (2013).

2. R. Nomura, H. Matsuda, R. Masumoto, K. Ueno and Y. Okuda, Macroscopic Quantum Tunneling and Avalanche Size Distribution of 4He Crystallization in Aerogel, J. Phys. Soc. Jpn. **80**, 123601 (2011).

PS3.23 Macroscopic Density Fluctuations and Metastable States of ^{3}He-^{4}He Solid Solutions in Pre-separation Region

K. A. Chishko, T. N. Antsygina, A. A. Lisunov, V. A. Maidanov, V. Y. Rubanskyi, S. P. Rubets, and E. Ya. Rudavskii

B.Verkin Institute for Low Temperature Physics and Engineering, Kharkov, Ukraine

A rigorous thermodynamic theory is applied to interpret the experimentally observed behavior of bulk ^{3}He-^{4}He mixed crystals at arbitrary concentrations $x_3 = 1 - x_4$ of the components. The experiments were performed using the precision barometry method on the solutions with $0.01 \leq x_3 \leq 0.9$. Temperature dependences of the pressure $P(T)$ in homogeneous solid mixtures have been studied both above and below the equilibrium phase separation temperature T_s. With decreasing temperature, as T_s is approached, the pressure increases instead of expected reduction due to decrease in the phonon contribution ($P_{ph} \sim T^4$). Such an increase in pressure continues in the metastable region below T_s until the spinodal temperature where the mixture separates inevitably. Theoretical interpretation of the observed effects shows that the found pressure behavior can be described only with the consistent account for fluctuations in the impurity subsystem which near T_s dominates over phonon contribution into the pressure. The obtained theoretical results are in good quantitative agreement with the experimental data. Density fluctuations give rise to a spontaneous formation of impuriton nano-clusters containing several hundreds of atoms. This estimated size of the fluctuating nano-clusters agrees quantitatively with the corresponding value obtained from the Lifshis-Slesov phenomenological theory of homogeneous nucleation.

1. T.N. Antsygina, A.A. Lisunov, V.A. Maidanov, V.Y. Rubanskyi, S.P.Rubets, E.Ya. Rudavskii, and K.A.Chishko, Physica B: Condensed Matter, **406**, 3870 (2011).

PS3.24 Gas-Solid Phase Transition in Hardcore-like Systems

K. Yamashita[a], Y. Kwon[b], and D. Hirashima[c]

[a]Department of Physics, Nagoya University, Japan

[b]Division of Quantum Phases and Devices, School of Physics, Konkuk University, Korea

[c]College of Liberal Arts Division of Arts and Sciences, International Christian University, Japan

It is known that classical hard spheres undergo a phase transition, the Alder transition, from a gas state to a solid state as the system is compressed. A ground state phase diagram of quantum hardcore bosons was also studied and it was also found that the quantum hardcore bosons localize at much more lower density than the classical counterpart. Their result implies that the quantum hardcore systems are much unstable toward solidification and the quantum effect can help the solidification of bose gases. But the quantum effect, the effect of the zero point motion, on the solidification has not been studied carefully except for the variational study by Nosanow *et al.*, where they found no evidence of the solid state stabilized by the zero point motion. The purpose of our work is to examine the effect of the zero point motion on the solidification of quantum systems by studying the gas-solid phase transition where particles interact with hardcore-like potentials. We calculated the ground state energies of each phase using the Quantum Monte Carlo method, and then, we found that the liquid phase is more stabilized as the effect of the zero point motion increases, that is, the quantum effect never help the solidification at zero temperature. This time, we study the quantum effect on the gas-solid phase transition at "finite temperature". A competition between thermal fluctuation and zero point motion would cause a crossover from the classical phase transition to the quantum one. In this crossover region, the solid phase would be stabilized by the quantum effect.

PS3.25 On the Lifetime of Metastable Metallic Hydrogen

L. B. Dubovskii and S. N. Burmistrov

Kuchatov Institute, Moscow, Russia

In connection with the recent experiments[1] we analyze stability of metallic hydrogen against nucleation of the stable molecular phase below the transition pressure P_c ~300 – 500 Gpa. The nucleation dynamics is governed by the tunneling of a critical molecular nucleus through a potential barrier in the low temperature region and by the thermal activation mechanism at high temperatures. In a wide region of pressures below the transition pressure $0.1P_c < P < P_c$ the critical nucleus of the molecular phase contains a large number of particles and has a large critical radius as compared with the interatomic spacing. The main reason for the large critical nucleus lies in the impossibilty to form a bound state of two hydrogen atoms, i.e. molecule, under high extrinsic electron density of the metallic phase at about r_s ~1.7. This results in the necessity of a density fluctuation yielding a void inside the metallic phase with the low electron density in the center so that the formation of molecules would become energetically favorable. The nucleation dynamics of molecular nuclei both at low and high temperatures can be described within the framework of the macroscopic approach. Within the above-mentioned $0.1P_c < P < P_c$ pressure region the lifetime of the metallic hydrogen phase proves to be practically infinite. In the low pressure region $P < 0.1P_c$ the formation of a void in the metallic state cannot be suppressed with the applied external pressure and the critical nucleus amounts to a few particles or less as the external pressure vanishes. Thus, we expect the opposite behavior with too small lifetime of the metastable metallic state, resulting in practically instant decay of the metallic hydrogen at low pressures.

1. M.I. Eremets and I. A. Trojan, Nature Materials **10, 927 (2011).**

PS3.26 Magnetic resonance study of atomic hydrogen and deuterium in solid H_2 and D_2 matrices below 1 K

Janne Ahokas[a], Sergey Sheludiakov[a], Jarno Järvinen[a], Otto Vainio[a], Sergey Vasiliev[a], Shun Mao[b], Vladimir Khmelenko[b], and David Lee[b]

[a]Wihuri Physical Laboratory, Department of Physics and Astronomy, University of Turku, Finland

[b]Department of Physics and Astronomy, Texas A&M University, College Station TX77843, USA

We have carried out the first experiments with H and D atoms embedded in solid H_2/D_2 films at temperatures below 1 K. The H_2/D_2 films were deposited onto the cold (<1 K) surface of quartz microbalance which served also as a mirror for a 128 GHz electron spin resonance (ESR) spectrometer. Atomic impurities were created by running an RF discharge in the sample cell [1]. For the first time we studied at temperatures below 1 K the quantum isotopic exchange reactions D+H_2=H+HD and D+HD=H+D_2, which effectively increase the concentration of atomic hydrogen in the system. Overall densities of H and D reached a record high value of 6×10^{19} cm^{-3} with the ratio $n_H/n_D = 7/3$. We observed dynamic nuclear polarization (DNP) of both H and D atoms. Positive nuclear polarization could be created by the Overhauser effect. Negative nuclear polarization could be created in ensembles of H atoms by the Solid effect or by ESR pumping a region close to the center of the H and D ESR spectrum. We discuss efficient population transfer via the forbidden transitions and possible transfer of nuclear polarization between H and D atoms.

1. J. Ahokas *et al.*, Phys. Rev. B 81, 104516 (2010).

PS3.27 Helium Buckyballs on the H_2-preplated C_{20} Surface

S. Park, S. Shim, and Y. Kwon

Division of Quantum Phases and Devices, School of Physics, Konkuk University, Seoul, Korea

We have performed path-integral Monte Carlo calculations to study the adsorption of ^4He atoms on the H_2-preplated C_{20} molecular surface. It is found that the H_2 monolayer on C_{20} is completed with 32 H_2 molecules to become a commensurate solid where each H_2 molecule is located either above one of the twelve pentagon centers or above one of the twenty carbon atoms. The radial density distribution of ^4He atoms adsorbed on the $(H_2)_{32} - C_{20}$ surface shows the first helium layer being located at a distance of 8.3 $\AA$ from the C_{20} molecular center. The angular density profiles of the ^4He adatoms reveal different quantum states, especially different buckyball structures, as the number of ^4He atoms N varies. While it is in a liquid state at low helium coverage, the ^4He layer exhibits an icosidodecahedron structure for N=30 where three ^4He atoms form a triangular face centered at one of twenty carbon atoms and each ^4He atom is shared between two neighboring triangular faces. This is found to be the lowest-energy state of the first helium layer on the H_2-preplated C_{20} molecular surface. For N=60, the ^4He atoms are located at 60 vertices of a truncated icosahedron with 12 pentagon and 20 hexagon faces. As more ^4He atoms are added beyond N=60, the additional atoms are found to be placed at the centers of the hexagon faces of the truncated icosahedrons and each of all 20 hexagon centers is occupied by a single ^4He atom to form a hexakis truncated icosahedron for N=80. Finally, by computing the superfluid fraction of the first ^4He layer on the $(H_2)_{32} - C_{20}$ surface as a function of N, we analyze the interplay between various buckyball structures exhibited by this helium layer and its superfluid response.

PS3.28 Dynamic nuclear polarization and relaxation in Si:P at very low temperatures

J. Järvinen[a], S. Vasiliev[a], D. Zvezdov[a,b], J. Ahokas[a], S. Sheludyakov[a], O. Vainio[a], T. Mizusaki[c], Y. Fujii[c], S. Mitsudo[c], M. Gwak[d], and S. Lee[d]

[a]Department of Physics and Astronomy University of Turku, 20014 Turku, Finland

[b]Kazan Federal University, 420008 Kremlyovskaya str., Kazan, Russia

[c]Research Center for Development of Far-Infrared Region, University of Fukui, Fukui, Japan

[d]Division of Materials Science, Korea Basic Science institute

We report on studies of dynamic nuclear polarization (DNP) and nuclear and electronic relaxation times of ^{31}P donors in natural Si. After the pioneering work of Feher [1] the recent interest towards this system has been raised by the proposal of Kane [2] to utilize impurity atoms for quantum computing.

The samples were studied in strong magnetic field and temperatures below 1K. At these conditions donor electron spins are fully polarized and electron and nuclear relaxation times are very long. The DNP in such conditions is very efficient and pumping with very low RF powers (<1 μW) for reasonably short time (≈1 hour) gives very high nuclear polarization of ^{31}P. DNP on the neighbouring ^{29}Si nuclei reduces strongly the ESR linewidth of ^{31}P. We discuss favourable conditions for DNP and possible physical mechanisms of the observed phenomena.

[1] G. Feher, Phys. Rev. **114**, 1219 (1959).

[2] B.E. Kane, Nature, **393**, 133 (1998).

[3] S. Vasilyev, J. Järvinen, E. Tjukanoff, A. Kharitonov, and S. Jaakkola, Rev. Sci. Instrum. **75**, 94 (2004).

PS3.29 **Enhancement of the magnetic flux in a superconducting system of the multiple thin strips**

Aliakbar Babaei-Brojeny[a] and Reza Sheikhi, Milad Sadeghi[b]

[a]Department of Physics, Isfahan University of Technology,Isfahan, Iran

[b]Department of Physics, Isfahan University of Technology,Isfahan, Iran

The main purpose of this article is to investigate the flux-focusing effect [1] in a superconducting system of multiple long parallel coplanar superconducting thin strips carrying the overall subcritical currents in perpendicular applied magnetic field when there is no net magnetic flux through the slots except the central slot; i.e. we calculate the effective area of the central slot, which is the area that would intercept the total magnetic flux in a uniform magnetic field flux density $\mathbf{B}_{\mathrm{a}} = \mu_0 H_a$,when the system of strips is in a perpendicular applied magnetic field H_a[1,2]. To do so, first we present the numerical solution for the Meissner-state magnetic-field and current-density distributions for the system and then we show that for narrow superconducting strips the effective area is substantially increased as the number of the strips is increased, which is an indication of concentrating the magnetic flux in the central slot.

1. A. A. Babaei-Brojeny and J. R. Clem, Supercond. Sci. Technol. 17 1275 (2004).
2. A. B. M. Jansman, M. Izquierdo, A. Eiguren, J. Flokstra and H. Rogalla, Appl.Phys. Lett., 72, 3515 (1998).

PS3.30 **Bose-Einstein condensation of collective Cooper pairs**

C. Ramirez[a] and C. Wang[b]

[a]Departamento de Fisica, Facultad de Ciencias, Universidad Nacional Autonoma de Mexico, Mexico

[b]Instituto de Investigaciones en Materiales, Universidad Nacional Autonoma de Mexico, Mexico

In this work, we present a new evidence to support the view point that the superconductivity could be a Bose-Einstein condensation (BEC). It is well known that the Cooper pairs are not true bosons[1] and then, we introduce the concept of collective Cooper pairs (CCP) through a unitary transformation of Cooper pairs[2]. We further prove that they accomplish bosonic commutation relations at the dilute limit[3], being able to accumulate many of them at a single quantum state, in contrast to the standard Cooper pairs. Next, we rewrite the Bardeen-Cooper-Schrieffer (BCS) Hamiltonian and its ground state in terms of collective Cooper pairs. An exact solution of all single-pair eigenstates is found by means of a multishell model and an analytical freedom-degree reduction technique. In particular, this solution becomes analytical at the thermodynamic limit and the obtained energy spectrum is used to determine the BEC temperature of CCP.

1. Bardeen J., Cooper L.N. and Schrieffer J.R. (1957) Phys. Rev. 108, 1175.

2. Ramirez C. and Wang C. (2009) Phys. Lett. A 373, 269.

3. Ramirez C. and Wang C. (2011) J. Phys. Chem. Solids 72, 395.

PS3.31 Simultaneous Measurements of Torsional Oscillator and Shear Modulus of Solid Helium-4 with 1 ppb ^{3}He impurity

J. Shin[a], J. Choi[a], S. Jang[a], E. Kim[a], and K. Shirahama[b]

[a]Center for Supersolid & Quantum Matter Research and Department of Physics, KAIST, Daejeon 305-701, Republic of Korea

[b]Department of Physics, Keio University, Yokohama 223-8522, Japan

To understand the connection between the torsional oscillator (TO) response and shear modulus change of solid helium, we measured the resonant period of TO and the shear modulus simultaneously. A pair of concentric piezo transducers is inserted into the annulus of the TO cell. The pzt transducers allow us to measure the shear modulus of solid helium in the annulus during the measurements of TO period. We found that the TO response was influenced by the change of shear stress applied by a drive pzt. However, the magnitude of suppression and relaxation time between two measurements show discrepancies. In addition, we investigated the hysteric behavior of shear modulus anomaly with various applied drive and frequency to compare with the change of TO period.

[1] E. Kim and M. H. W. Chan Nature 427, 225-227 (2004)

[2] J. Day and J. Beamish Nature 450, 853-856 (2007)

PS3.32 Observation of NCRI in Solid Helium-4 by using Rigid Double Pendulum Torsional Oscillator

Jaewon Choi, Jaeho Shin, and Eunseong Kim

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

The period drop in the torsional oscillator (TO) containing solid helium-4[1,2] was attributed to the shear modulus change[3] that influences the rigidity of the TO cell. Although negligible in an ideally rigid torsional oscillator[4], the influence of shear modulus effect can be amplified due to non-rigid structures in TOs.[5,6,7] Therefore, it is essential to design a rigid TO in order to eliminate various elastic effects, and to examine whether the TO response is caused by the appearance of superfluidity or not. We made a rigid TO cell consisted with double torus of which resonant frequencies are 432Hz for in-phase and 1095Hz for out-of-phase. Here we will report the preliminary study on the frequency dependence of the TO response.

1. E. Kim and M. H. W. Chan, Nature 427, 225 (2004)
2. E. Kim and M. H. W. Chan, Science 305, 1941 (2004)
3. J. Day and J. Beamish, Nature 450, 853 (2007)
4. A. C. Clark, J. D. Maynard, M. H. W. Chan, Phys. Rev. B 77, 184513 (2008)
5. J. D. Reppy, X. Mi, A. Justin, E. J. Mueller, Journal of Low Temperature Physics 168, 175 (2012)
6. J. R. Beamish, A. D. Fefferman, A. Haziot, X. Rojas, S. Balibar, Phys. Rev. B 85, 180501 (2012)
7. H. Maris, Phys. Rev. B 86, 020502 (2012)

PS3.33 Stability limit of a metastable state of hcp solid helium-4

F. Souris[a], J. Grucker[b], P. Jacquier[b], and J. Dupont-Roc[b]

[a]Laboratoire de Physique Statistique, ENS, Paris, France

[b]Laboratoire Kastler Brossel, ENS, Paris, France

Solid helium has the unique feature of having an horizontal melting curve in the P,T plane. This offers novel opportunities to study the stability limits of a metastable solid, by using the pressure as a control parameter of the metastability. We produce a metastable sample by focusing inside the crystal a 1 MHz ultrasonic sound pulse that matches the anisotropic compressional wavesurface of solid helium-4. The density of the metastable state is addressed by using an interferometric imaging technique. We found that 4 bar below the melting pressure, the metastable crystal seems to reach its stability limit. This instability occurs at much higher pressure than those predicted by nucleation theory or Monte-Carlo simulations. Repeated experiments show that the instability initially appears during negative pressure swings, as a small defect ($\sim$ 0.2 mm) located at the maximum isotropic strain. Further studies are performed to understand the underlying mechanism of the instability. Possible scenarios accounting for this unexpected observation are discussed.

PS3.34 Magnon BEC in $RbMnF_3$ and $MnCO_3$ at a temperature about 1 K

D. Konstantinov[a], Yu.M. Bunkov[b], C. Deans[c], N. Desai[a], A.O. Badrutdinov[a], and L.V. Abdurakhimov[a]

[a]Okinawa Institute of Science and Technology, Japan

[b]Institute Neel, CNRS, Grenoble, France

[c]University of Oxford, Magdalen College, England

The Bose-Einstein condensation (BEC) of magnons and Spin Superfluidity were discovered in 1984 in superfluid ^{3}He-B.[1] Recently the magnon BEC was demonstrated in solid antiferromagnets.[2] Here we report a very recent results of magnon excitation and its Bose-Einstein condensation in antiferromegnets with dynamical shift of Nuclear Magnetic Resonance (NMR). We have investigated BEC in $RbMnF_3$ with cubic anisotropy and $MnCO_3$ with easy plain anisotropy. Both crystals are characterized by a very non-linear NMR with the energy potential which supports the formation of BEC of magnons. Owing a relatively small relaxation at the temperature of about 1K we have succeeded to create the BEC states of high density. The new results of magnon BEC under these conditions will be demonstrated.

1. Borovik-Romanov A.S., Bunkov Yu.M., Dmitriev, V.V. Mukharskiy Yu.M. JETP Letters 40, 1033 (1984); Fomin I.A. JETP Lett. 40, 1037 (1984).

2. Bunkov, Yu.M., Alakshin, E.M. Gazizulin, R.R., Klochkov A.V., Kuzmin V.V., L'vov V.S., Tagirov M.S., Phys. Rev. Lett. 108, 177002 (2012).

PS3.35 Ground-State Energy and Condensate Density of a Dilute Bose Gas Revisited

K. Tsutsui and T. Kita

Department of Physics, Hokkaido University, Japan

The ground-state energy per particle E/N and condensate density n_0 of a dilute Bose gas are studied with a self-consistent perturbation expansion satisfying the Hugenholtz-Pines theorem and conservation laws simultaneously.[1)] A new class of Feynman diagrams for the self-energy, which has escaped consideration so far, is shown to add an extra constant $c_{\rm ip} \sim O(1)$ to the well-known expressions reported by Lee, Huang, and Yang[2)] as

$$\frac{E}{N} = \frac{2\pi\hbar^2 an}{m}\left[1+\frac{16}{5}\left(\frac{8}{3\sqrt{\pi}}+c_{\rm ip}\right)\sqrt{a^3n}\right], \qquad \frac{n_0}{n} = 1-\left(\frac{8}{3\sqrt{\pi}}+c_{\rm ip}\right)\sqrt{a^3n}\,,$$

where a, n, and m are are the s-wave scattering length, particle density, and particle mass, respectively.[3)] We present a couple of estimates for $c_{\rm ip}$; the third-order perturbation expansion yields $c_{\rm ip} = 0.412$. The existence of such an additional contribution is also suggested by a previous diffusion Monte Carlo simulation.[4)]

1) T. Kita, Phys. Rev. B **80** 214502, (2009). 2) T. D. Lee, K. Huang, and C. N. Yang, Phys. Rev. **106** 1135, (1957). 3) K. Tsutsui and T. Kita, J. Phys. Soc. Jpn. **82** 063001, (2013). 4) S. Giorgini, J. Boronat, and J. Casulleras, Phys. Rev. A **60** 5129, (1999).

PS3.36 Precursor phenomena of nucleations of quantized vortices in the presence of a uniformly moving obstacle in Bose-Einstein condensates

M. Kunimi and Y. Kato

Department of Basic Science, The University of Tokyo, Tokyo 153-8902, Japan

The motion of the macroscopic object above a critical velocity in superfluids triggers breakdown of superfluidity due to nucleations of quantized vortices. Many experimental[1] and theoretical[2] studies about these phenomena have been done. However, the underlying mechanism of the nucleation of the vortices are still unclear.

We investigate the stability of Bose-Einstein condensates confined in a finite size torus with a uniformly moving Gaussian potential by solving the Gross-Pitaevskii and the Bogoliubov equations. We show that the system does not exhibit both the Landau and the dynamical instability. The first excited energy(energy gap) obeys a scaling law near the critical velocity. This means that dynamical critical phenomena occur in this system. We also find the enhancement of low-energy dynamical local density fluctuations near the critical velocity. These phenomena can be regarded as precursor phenomena of the nucleation of quantized vortices.

1 C. Raman, *et al.*, Phys. Rev. Lett. **83**, 2502 (1999), R. Onofrio, *et al.*, Phys. Rev. Lett. **85**, 2228 (2000), S. Inouye, *et al.*, Phys. Rev. Lett. **87**, 080402 (2001), T. W. Neely, *et al.*, Phys. Rev. Lett. **104**, 160401 (2010), K. C. Wright, *et al.*, Phys. Rev. Lett. **110**, 025302 (2013).

2 T. Frisch, *et al.*, Phys. Rev. Lett. **69**, 1644 (1992), K. Sasaki, *et al.*, Phys. Rev. Lett. **104**, 150404 (2010), K. Fujimoto, and M. Tsubota, Phys. Rev. A, **83**, 053609 (2011).

PS3.37 Self-consistent multi-soliton solutions in Bogoliubov-de Gennes systems

D. A. Takahashi and M. Nitta

Department of Physics, and Research and Education Center for Natural Sciences, Keio University, Hiyoshi 4-1-1, Yokohama, Kanagawa 223-8521, Japan

The Bogoilubov-de Gennes (BdG) equation and the gap equation (the self-consistent condition) describe spatially inhomogeneous states in various kinds of condensed matter systems, such as superconductors, polyacetylene [1], and ultracold atomic Fermi gases. The equivalent equations also appear in the mean field theory of the Gross-Neveu model in high-energy physics [2]. It is generally a difficult problem to obtain a self-consistent exact solution satisfying not only the BdG equation but also the gap equation, and only a few analytic examples were known so far such as the one- and two-kink (polaron in polyacetylene) [1-3] and the kink-crystal [4]. In our presentation, we show the most general condition for the multi-soliton solutions to satisfy the gap equation [5]. We show that the occupation numbers of bound states around each of solitons determine the soliton's phase shift, which must be discretized. We also show a new result on the self-consistent condition of the system consisting of only right-movers.

1. H. Takayama, Y. R. Lin-Liu, and K. Maki, PRB **21**, 2388 (1980).
2. R. F. Dashen, B. Hasslacher, and A. Neveu, PRD **12**, 2443 (1975).
3. S. Okuno and Y. Onodera, JPSJ **52**, 3495 (1983).
4. S. A. Brazovskii, S. A. Gordyunin, and N. N. Kirova, JETP Lett. **31**, 456 (1980); B. Horovitz, PRL **46**, 742 (1981).
5. D. A. Takahashi and M. Nitta, PRL **110**, (2013) 131601.

PS3.38 Quantum phase slips of trapped superfluid Bose gases in one dimension

Ippei Danshita

Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto, Japan

We study transport of trapped one-dimensional superfluids in connection with quantum phase slips.[1] We specifically consider damping of dipole oscillations induced by sudden displacement of the trapping potential, which has been investigated in previous experiments. We find a broad parameter region in which the damping rate of the oscillation is proportional to the nucleation rate of a quantum phase slip divided by the flow velocity and exhibits a power-law behavior with respect to the flow velocity. From this relation and simulations with the exact time-evolving block decimation method, we argue that the suppression of the 1D transport observed in the experiments is mainly due to quantum phase slips. We suggest that the damping rate at a finite temperature exhibits a universal crossover behavior upon changing the flow velocity.

1. Danshita, I. (2013), "Universal damping behavior of dipole oscillations of one-dimensional ultracold gases induced by quantum phase slips". arXiv:1303.1616v1.

PS3.39 Spin turbulence in spin-1 spinor Bose-Einstein condensate with antiferromagnetic interaction

K. Fujimoto and M. Tsubota

Department of Physics, Osaka City University, Japan

We theoretically and numerically study turbulence in spin-1 spinor Bose-Einstein condensates (BECs) with antiferromagnetic (AF) interaction by using the spinor Gross-Pitaevskii equation. In this system, the dynamical instability is caused by the counterflow, leading to the disturbed distribution of the spin density vector, which we call spin turbulence (ST) [1]. Previously, we investigate the ST in spin-1 spinor BEC with ferromagnetic interaction, finding that the spectrum of spin interaction energy exhibits the -7/3 power law [1]. In classical and quantum turbulence, the spectrum of kinetic energy is known to show the Kolmogorov $-5/3$ power law [2,3], but we found another power law in the ST. In this study, we investigate the ST in the spin-1 spinor BEC with AF interaction, showing the -1 and -7/3 power laws in the low and high wave number regions, respectively. These power laws can be obtained by the scaling analysis for the equations of spin density vector and nematic density tensor. However, our numerical calculation finds the -7/3 power law in the high wave number region, while the spectrum in the low wave number region deviates from the -1 power law.

1. K. Fujimoto and M. Tsubota, Phys. Rev. A 85, 033642 (2012); Phys. Rev. A 85, 053641 (2012).
2. U. Frisch, *Turbulence* (Cambridge University Press, Cambridge, 1995).
3. *Progress in Low Temperature Physics*, edited by W. P. Halperin and M. Tsubota, Vol. 16 (Elsevier, Amsterdam, 2009).

PS3.40 Spin-glass-like behavior of spin turbulence in spinor Bose-Einstein condensates

Yusuke Aoki, Kazuya Fujimoto, and Makoto Tsubota

Department of Physics, Osaka City University, Japan

We numerically study spin turbulence (ST) in spin-1 spinor Bose-Einstein condensates with ferromagnetic and antiferromagnetic interaction by solving the Gross-Pitaevskii equation. In the previous study[1] for ST with ferromagnetic interaction, the directions of the spin density vectors were found to be spatially disordered but temporally frozen. This behavior of ST is similar to that of spin glass. In this study, to characterize the "spin-glass-like" behavior, we calculate the order parameter of the spin glass. In ST with ferromagnetic interaction, we confirm the growth of the order parameter, which indicates that ST behaves like spin glass. On the other hand, in ST with antiferromagnetic interaction, we find that the order parameter does not grow. This means that spin density vectors temporally fluctuate, not being frozen. We suppose that whether the order parameter grows or not is caused by the different property of the dispersion relation in the low wave number region.

1. K. Fujimoto, and M. Tsubota, *Phys. Rev. A* **85**, 053641 (2012)

PS3.41 Diffusion of Vortices to 'Extra-Dimension' in Tachyon Condensation via Domain Wall Annihilation in Segregated Bose-Einstein Condensates

H. Takeuchi[a], K. Kasamatsu[b], M. Tsubota[c], and M. Nitta[d]

[a]Department of Physics, Osaka City University, Japan

[b]Department of Physics, Kinki University, Japan

[c]Department of Physics and The Osaka City University Advanced Research Institute for Natural Science and Technology (OCARINA), Osaka City University, Japan

[d]Department of Physics and Research and Education Center for Natural Sciences, Keio University, Japan

In our previous work[1], it is proposed that a domain-wall annihilation in two-component Bose-Einstein condensates causes tachyon condensation accompanied by spontaneous symmetry breaking in a two-dimensional subspace. Here, three-dimensional vortex formation from domain-wall annihilations is considered kink formation in the two-dimensional subspace along the walls. In this sense, the dimension perpendicular to the subspace may be called an 'extra-dimension'. In this work, we investigate how the diffusion of vortices to the 'extra-dimension' influences the relaxation dynamics of the tachyon condensation.

1. Takeuchi, H., Kasamatsu, K., Tsubota, M., and Nitta, M. (2012) "Tachyon Condensation Due to Domain-Wall Annihilation in Bose-Einstein Condensates", Phys. Rev. Lett. **109**, 245301.

PS3.42 Instability of Counter-rotating Vortices in miscible two-component Bose-Einstein condensates

S. Ishino[a], H. Takeuchi[a], and M. Tsubota[a,b]

[a]Department of Physics, Osaka City University, Osaka, Japan

[b]The OCU Advanced Research Institute for Natural Science and Technology, Osaka City University, Osaka, Japan

We theoretically study instability and nonlinear dynamics of multi-quantum vortices in trapped two-component Bose–Einstein condensates. We consider that each condensate has a multi-quantum vortex at the center; the two vortices have same amplitude of winding number with opposite sign. These counter-rotating multi-quantum vortices are expected to split into some vortices as multi-quantum vortices in a single-component BEC. However, we find that the vortices show novel splitting and nucleation of vortices by numerically solving the Gross–Pitaevskii equations. These dynamics are predicted by two kinds of linear analysis. One is numerically solving the Bogoliubov-de Gennes equation. The other is a local density approximation with the dispersion relation of the Bogoliubov excitations in countersuperflow, two counter-propagating uniform miscible superfluids. The countersuperflow is dynamically unstable when the relative velocity exceeds a critical value[1,2]. The instability of the counter-rotating vortices has a deep connection with the instability of countersuperflow.

1. H. Takeuchi, S. Ishino, and M. Tsubota, Phys. Rev. Lett. **105**, 205301 (2010).
2. S. Ishino, M. Tsubota, and H. Takeuchi, Phys. Rev. A. **83**, 063602 (2011).

PS3.43 Characterization of an apparatus and theoretical predictions for a two species BEC turbulence experiment

K. J. Thompson, E. Pedrozo-Peñafiel, and V. S. Bagnato

Instituto de Física de São Carlos, USP

The observation of superfluid turbulence in ^{87}Rb[1] introduced the experimental tools of atomic optics into the world of quantum fluid dynamics. Prior to this experimental realization, quantum turbulence research has only been conducted in cryogenic helium which often requires large and cumbersome apparatus. Atomic optical apparatus on the other hand, fit well on a single tabletop and allow for unprecedented measurement precision and access to the experimental volume. The work reported on here is an evolution of our previous work in ^{87}Rb[1], where we study the properties of a turbulent BEC, however in this apparatus we investigate turbulence in two miscible atomic species, Na and K. For this, we have constructed and characterized a new apparatus where two separate 2D MOTs are used to deliver atoms into a joint optical dipole trap. In the optical trap the two samples elements are simultaneously cooled. In this report we present both the experimental designs, apparatus specifications and measurements, in addition to theoretical predictions and computations for proposed future experiments.

1. Henn, E. A. L. and Seman, J. A. and Roati, G. and Magalhães, K. M. F. and Bagnato, V. S. (2009). "Emergence of Turbulence in an Oscillating Bose-Einstein Condensate", 103 Physical Review letters.

PS3.44 Observation of anomalous momentum distribution in a turbulent Bose-Einstein Condensate

G. Telles, G. G. Bagnato, and V. S. Bagnato

Instituto de Física de São Carlos, Universidade de São Paulo Caixa Postal 369, 13560-970 São Carlos, São Paulo, Brazil

Bose condensed gaseous samples in the superfluid regime may present the simplest form of turbulence, due to their velocity field constrains, and be a gateway for the better understanding of such complex phenomenon. Trapped Bose-Einstein condensates have unparalleled control over many experimental parameters, such as dimensionality, density, trapping potential, and atomic interactions. Additionally, Bose condensed gasses can be measured by several *in situ* techniques allowing for dynamic studies.[1,2] The emergence of quantum turbulence observed in a magnetically trapped sample of ^{87}Rb BEC was investigated. Vortices and anti-vortices were nucleated using a controlled sinusoidal external magnetic field gradient that twisted the superfluid sample injecting kinetic energy. The vortices spread all over the cloud, setting up the experimental conditions for the turbulent regime to rise. The atomic cloud was then allowed to freely expand and an anomalous momentum distribution density was observed and studied. Time-of-flight absorption images were acquired and the turbulent and non-turbulent condensates were compared. Clear deviations from the Thomas-Fermi (non-turbulent momentum distribution) were observed in the expanding turbulent clouds.

1. Freilich, D., Bianchi, D., Kaufman, A., Langin, T., and Hall, D. (2010). Science **329**, 1182.

2. Ketterle, W., Durfee, D.S., and Stamper-Kurn, D.M. (1999). arXiv:cond-mat/9904034v2.

PS3.45 Implementation of Lattice Gauge-Higgs Model in Quantum Simulators of Cold Atoms

Kenichi Kasamatsu[a], Ikuo Ichinose[b], and Tetsuo Matsui[a]

[a]Department of Physics, Kinki University, Higashi-Osaka, Osaka 577-8502, Japan

[b]Department of Applied Physics, Nagoya Institute of Technology, Nagoya 466-8555, Japan

In this work, we show how to implement the U(1) gauge-Higgs model with asymmetric nearest-neighbor Higgs coupling by using a system of cold atoms in an optical lattice[1]. The gauge-Higgs coupling in the imaginary time direction naturally arises from the violation of the U(1) local gauge invariance of the simulators caused by the deviation from the fine-tuned system parameters. A general method to supply the Higgs coupling in all space-time directions may be realized by coupling atoms in an optical lattice to another particle reservoir filled with the Bose-condensed atoms via laser transitions. Clarification of the dynamics of this gauge-Higgs model sheds some lights upon various unsolved problems including the inflation process of the early universe. We study the phase structure of this model by Monte Carlo simulation, and also discuss the atomic characteristics of the Higgs phase in each simulator.

1. K. Kasamatsu, I. Ichinose, and T. Matsui, arXiv:1212.4952.

PS3.46 Spin-Orbit Coupled Bose-Einstein Condensates in Optical Lattices

Ben Li and Hidetsugu Sakaguchi

Department of Applied Science for Electronics and Materials, Kyushu University, Japan

We study theoretically the ground state of Bose gas with synthetic spin-orbit coupling in two-dimensional optical lattices, showing that a vortex lattice state will appear because the interplay between optical lattices potential, spin-orbit coupling and spin-dependent atomic interactions. We obtained the Bloch state for Gross-Pitaevskii equation(GPE) without the nonlinear terms by numerical and analysis calculations, and compared with stationary solutions to the GPE with nonlinear terms. In the case that the interatomic interaction is weaker compare with intra-atomic one, the vortex lattice state will into a ferromagnetic order. In the other case, the state will into a complicated phase consists of ferromagnetic and antiferromagnetic orders.

PS3.47 Elementary excitations of antiferromagnetic spin-1 bosons in an optical lattice

M. Shinozaki[a], S. Tsuchiya[b], S. Abe[b], T. Ozaki[b], and T. Nikuni[b]

[a]Department of Basic Science, The University of Tokyo, Komaba, Meguro-ku, Tokyo 153-8902, Japan

[b]Department of Physics, Tokyo University of Science, Kagurazaka, Shinjuku-ku, Tokyo 162-8601, Japan

We study elementary excitations of spin-1 bosons with antiferromagnetic interaction in an optical lattice by applying the Gutzwiller approximation to the spin-1 Bose-Hubbard model. There appear various excitations with spin degrees of freedom in the Mott-insulator (MI) phase as well as in the superfluid (SF) phase. The ground state in the MI phase shows a remarkable parity effect in which even fillings stabilize the MI state due to formation of spin-singlet pairs[1,2]. We find that excitation spectra in the MI phase exhibit characteristic features that reflect the even-odd parity effect of the ground state. We clarify evolution of elementary excitations across the quantum critical point of the SF-MI transition.

1. S. Tsuchiya, et al., Phys. Rev. A **70**, 043628 (2004)
2. E. Demler and F. Zhou, Phys. Rev. Lett. **88**, 163001 (2002)

PS3.48 First-Order Phase Transition and Anomalous Hysteresis of Binary Bose Mixtures in an Optical Lattice

Daisuke Yamamoto[a], Takeshi Ozaki[b], Carlos A. R. Sá de Melo[c], and Ippei Danshita[d]

[a]Condensed Matter Theory Laboratory, RIKEN, Saitama, Japan

[b]Faculty of Business Administration and Information, Tokyo University of Science, Nagano, Japan

[c]School of Physics, Georgia Institute of Technology, Georgia, USA

[d]Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto, Japan

We study a first-order phase transition between superfluid and Mott insulator phases in binary Bose mixtures loaded into a hypercubic optical lattice.[1] The system is described by a two-component Bose-Hubbard model. We discuss the experimental feasibility of the first-order transitions and the accompanying hysteresis in terms of the required controllability of the lattice depth and the temperature to be achieved. We argue that the first-order transition phenomena could be simulated in current (or near-future) experimental techniques using, e.g., a binary mixture of ^{87}Rb atoms in two different hyperfine states. We also discuss an anomalous hysteresis behavior that appears when the chemical potential of the system is varied. In the anomalous hysteresis, the phase transition occurs in a unidirectional way and a hysteresis loop does not form. The underlying mechanism is explained by means of the Ginzburg-Landau theory.

1. Yamamoto, D., Ozaki, T., Sá de Melo, C. A. R., and Danshita, I. "First-order phase transition and anomalous hysteresis of Bose gases in optical lattices". arXiv:1304.2578.

PS3.49 Fermi superfluid on the Lieb lattice

C. Sato[a], H. Iramina[b], S. Tsuchiya[a], and T. Nikuni[a]

[a]Department of Physics, Tokyo University of Sciences, Japan

[b]Department of Engineering, Kyoto University, Japan

We investigate the superfluid state of ultracold fermions on the Lieb lattice. A unique feature of this system is that the single-particle energy band has a flat band crossing the Dirac point. We study the attractive Hubbard model on the Lieb lattice within the BCS-Leggett type of mean-field theory. We find non-uniform superfluid states with the three-sublattice structure, which arises from the lattice geometry. In the strong coupling BEC regime, we give a simple picture of the three-sublattice superfluid state based on the effective model for tightly-bound molecular bosons, or an equivalent pseudo-spin 1/2 system. In addition, we discuss the influence of the flat band and Dirac point on the superfluidity.

PS3.50 Time dependent Ginzburg-Landau formalism for two-bandgap Fermi systems

J. Tempere, S. N. Klimin, and J. T. Devreese

TQC, Universiteit Antwerpen, Belgium

Two-bandgap superconductors, such as magnesium diboride, exhibit interesting vortex structures such as stripe formation. These are seen to arising from a nonmonotonic intervortex interaction potential. Attempts have been made to describe these systems using a two component time-dependent Ginzburg-Landau (GL) equation describing two phenomenologically coupled order parameters. Whereas for a single-bandgap system, the single-component GL equation is microscopically validated (through the Gorkov formalism), this is not the case for the two-component system. After reviewing briefly the two bandgap superconductors, we focus in this talk on a realization of the two bandgap system through ultracold fermionic atoms, i.e. two-band superfluidity. Here, starting from the microscopic action functional of a four-component Fermi system, we use a path integral treatment to derive an effective action functional from which we can extract an extended time-dependent GL equation and corresponding free energy functional, valid over the entire temperature regime in stead of a small region near the phase transition. The GL coefficients obtained are analytical and easily tractable expression based on the microscopic theory. The two-band nature of the superfluid is exhibited through a hidden criticality of the susceptibility near the temperature corresponding to the smallest gap.

PS3.51 Superfluid theory of a gas of polarized dipolar Fermi molecules

Y. Endo[a], D. Inotani[b], and Y. Ohashi[a]

[a]Department of Physics, Faculty of Science and Technology, Keio University, Japan

[b]Graduate School of Pure and Applied Sciences, University of Tsukuba, Japan

We present a superfluid theory of a polarized dipolar Fermi gas. Starting from a model dipolar molecule consisting of two atoms with positive charge and negative charge, we derive a dipole-dipole pairing interaction, which is valid for *all* the momentum region. This effective interaction is quite different from the previous one [1], which is *not* valid for the large momentum region. Using this pairing interaction, we show that the resulting BCS gap equation is not suffered from the well-known ultraviolet divergence, without employing any regularization method. This is also in contrast to case using the previous dipolar interaction, where one needs to regularize the momentum-dependent interaction to eliminate the ultraviolet divergence. Using this cutoff-free BCS theory, we identify the symmetry of the pairing state realized in this system. We also discuss the deformation of the Fermi surface, originating from the anisotropic dipole-dipole interaction [2].

1. T. Shi, J. N. Zhang, C. P. Sun, and S. Yi, Phys. Rev. A **82**, 033623 (2010).
2. M. A. Baranov, Ł. Dobrek, and M. Lewenstein, Phys. Rev. Lett. **92**, 250403 (2004).

PS3.52 Spin Susceptibility and Strong Coupling Effects in an Ultracold Fermi Gas

H. Tajima, R. Hanai, R. Watanabe, and Y. Ohashi

Department of Physics, Faculty of Science and Technology, Keio University, Japan

We investigate magnetic properties and effects of strong pairing fluctuations in the BCS (Bardeen-Cooper-Schrieffer)-BEC (Bose-Einstein condensation) crossover regime of an ultracold Fermi gas. Using an extended T-matrix theory[1], we calculate spin susceptibility χ above the superfluid phase transition temperature $T_{\rm c}$. In the crossover region, we show that the formation of preformed Cooper pairs naturally leads to a non-monotonic temperature dependence of χ, which is similar to the so-called spin-gap phenomenon observed in the under-doped regime of high-T_c cuprates[2]. From this temperature dependence, we determine the spin-gap temperature as the temperature at which χ takes a maximum value, in the whole BCS-BEC crossover region. Since the spin susceptibility is sensitive to the formation of singlet Cooper pairs, our results would be useful in considering the temperature region where pairing fluctuations are important in the BCS-BEC crossover regime of an ultracold Fermi gas.

1. T. Kashimura, R. Watanabe, and Y. Ohashi, Phys. Rev. A **86** 043622 (2012).
2. Y. Yoshinari, H. Yasuoka, Y. Ueda, K. Koga, and K. Kosuge, J. Phys. Soc. Jpn. **59**, 3698 (1990).

PS3.53 **Non-Fermi Liquid Nature of the Two-dimensional Dipolar Fermi Gas**

J. Boronat[a] and E. Krotscheck[b,c]

[a]Departament de Física i Enginyeria Nuclear, Campus Nord B4-B5, Universitat Politècnica de Catalunya, E-08034 Barcelona, Spain

[b]Department of Physics, University at Buffalo, SUNY, Buffalo, New York 14260, USA

[c]Institute for Thoretical Physics, Johannes Kepler University, Linz, Austria

We have performed ground state calculations using the Fermi hypernetted-chain Euler-Lagrange method and fixed-mode Diffusion Monte Carlo calculations for the two-dimensional single-component dipolar Fermi gas. We find that already at very low densities the system has a topological instability of the Fermi disk against particle-hole excitations.

PS3.54 **Two-componet BEC for Studying Quantum Turbulence**

E. Pedrozo-Peñafiel, R. R. Paiva, P. Castilho, F. J. Vivanco, A. Kruger, K. Thompson, K. M. Farias, and V. S. Bagnato

Instituto de Física de São Carlos, Universidade de São Paulo, Brazil

In this work we are dealing with a mixture of Na/K Bose-Einstein Condensates (BEC). With the mixture of these two superfluids, we are going to investigate the effects of transferring quantum excitations, collective excitations and vortices, as well. Effects of modulation of the scattering length and excitation are being reviewed and will be object of investigation in the BEC of K and we will try to verify the thermalization with the second specie (Na). Our experimental system being mounted is a composition of two independently systems, Na and K. We are going to produce a trap of Na atoms from a 2D MOT [1] and the same for K. They will be combined to produce a single working chamber with two traps and finally the two condensates. In a previous work developed in our group [2] was reported the experimental observation of vortex tangles in an atomic Bose-Einstein condensate of 87Rb atoms applying an external oscillatory perturbation to the trap. Other characteristic signatures confirming the turbulence are also shown, such the suppression of the aspect ratio inversion typically observed in quantum degenerate bosonic gases during free expansion.

1. Lamporesi, G., et. al. (2013). “Compact high-flux source of cold sodium atoms”. Review of Scientific Instruments 84, 063102.

2. Henn, E. A. L., et. al. (2009). “Emergence of Turbulence in an Oscillating Bose-Einstein Condensate”. Physical Review Letters 103, 045301.

PS3.55 Exact Self-Consistent Condensates in (Imbalanced) quasi-1D Superfluid Fermi Gases

G. Marmorini[a], R. Yoshii[b], S. Tsuchiya[c], and M. Nitta[d]

[a]Condensed Matter Theory Lab, RIKEN, Japan

[b]YITP, Kyoto University, Japan

[c]Department of Physics, Tokyo University of Science, Japan

[d]Department of Physics, Keio University, Japan

Borrowing some techniques from high-energy physics, and in particular from the study of Nambu-Jona-Lasinio model in 1+1 dimensions, we present an analytic method to approach Eilenberger equation and the associated Bogoliubov-de Gennes equation for quasi-1D fermionic gases. The problem of finding self-consistent inhomogeneous condensates is reduced to solving a certain class of nonlinear Schrödinger equations, whose most general solitonic solution is indeed available. Previously known solutions can be retrieved by taking appropriate limits in the parameters. The applicability of the method extends to ring geometry and to population imbalanced Fermi gases. In particular we show exactly that fermionic zero-modes are robust against imbalance.

1. Basar, G. and Dunne, G. V. (2008). Phys. Rev. Lett. 100, 200404
2. Basar,G. and Dunne, G. V. (2008). Phys. Rev. D 78, 065022
3. Yoshii, R. Tsuchiya, S., Marmorini, G. and Nitta, M. (2011). Phys. Rev. B 84, 024503
4. Yoshii, R., Marmorini, G. and Nitta, M. (2012). J. Phys. Soc. Jpn. 81 094704

PS3.56 Variational description of the exchange-driven liquid-to-solid quantum phase transition in ^{4}He

Y. Lutsyshyn[a], C. Cazorla[b], G.E. Astrakharchik[c], and J. Boronat[c]

[a]Institut für Physik, Universität Rostock, 18051 Rostock, Germany

[b]Institut de Ciència de Materials de Barcelona (ICMAB-CSIC), 08193 Bellaterra, Spain

[c]Departament de Física i Enginyeria Nuclear, Universitat Politècnica de Catalunya, Campus Nord B4-B5, E-08034 Barcelona, Spain

We present a detailed study of a simple but accurate and exchange-symmetric wavefunction that was proposed for the ground state of solid helium [1]. It is shown that a direct variational optimization of this two-parameter wavefunction properly predicts the location of the melting transition of ^{4}He. Transition is also predicted to be of the first order. This allows us to study the phase transition variationally and the extend to which the Bose statistics of solid helium-4 influences both the solidification and the properties of the solid.

1. C. Cazorla, G.E. Astrakharchik, J. Casulleras, J. Boronat, "Bose–Einstein quantum statistics and the ground state of solid ^{4}He" New J. Phys. 11, 013047 (2009).

PS3.57 Self-consistent T-matrix approach to an interacting ultracold Fermi gas with mass imbalance

R. Hanai and Y. Ohashi

Department of Physics, Keio University, Japan

We investigate the superfluid phase transition in the BCS-BEC crossover regime of an ultracold Fermi gas with mass imbalance. In our previous paper[1], within the framework of an extended T-matrix approximation (ETMA), we showed that the superfluid phase transition temperature T_c vanishes in the weak-coupling BCS regime, when the ratio of mass imbalance becomes large to some extent. In our presentation, extending ETMA to include higher order pairing fluctuations within a self-consistent T-matrix level[2], we clarify that T_c actually remains finite even in the highly mass-imbalanced case. The key to obtain this finite T_c is found to be a consistent treatment of μ_L and μ_H in the gap equation (where μ_L and μ_H are the chemical potentials of the light mass component and heavy mass component, respectively). Using this strong-coupling theory, we also determine the phase diagram of a Fermi gas in terms of temperature, interaction strength, and the ratio of mass imbalance. Since Fermi condensates with mass imbalance have been recently discussed in various systems, such as a ^{40}K-^{6}Li Fermi gas, exciton-polariton condensate, and color superconductivity, our results would be useful in understanding physical properties of these novel Fermi superfluids.

1. R. Hanai, T. Kashimura, R. Watanabe, D. Inotani, and Y. Ohashi, J. Low Temp. Phys. **171**, 389 (2013).

2. R. Haussmann, Z. Phys. B **91**, 291 (1993).

PS3.58 Vortex polygons and their stabilities in Bose-Einstein condensates and field theory

M. Kobayashi[a] and M. Nitta[b]

[a]Department of Physics, Kyoto University, Oiwake-cho, Kitashirakawa, Sakyo-ku, Kyoto, 606-8502, Japan

[b]Department of Physics, and Research and Education Center for Natural Sciences, Keio University, Hiyoshi 4-1-1, Yokohama, Kanagawa 223-8521, Japan

We study vortex polygons and their stabilities in miscible two-component Bose-Einstein condensates, and find that vortex polygons are stable for the total circulation $Q \leq 5$, metastable for $Q = 6$, and unstable for $Q \geq 7$. As a related model in high-energy physics, we also study the vortex polygon of the baby-Skyrme model with an anti-ferromagnetic potential term, and compare both results.

Invited Oral Presentations: Monday August 5th

P5.1 Topological Superconductors and Superfluids

Y. Maeno

Department of Physics, Kyoto University, Kyoto 606-8502, Japan

Triggered by the recent predictions and subsequent experimental confirmation of "topological insulators", topological classification of materials provides new insights into investigations of novel "topological quantum phenomena" in superconductors and superfluids. We will first review topological classification of materials and the associated topological edge states. We then focus on the topological quantum phenomena in Sr_2RuO_4, a leading candidate of the "$p+ip$" topological superconductor belonging to the same topological class as the superfluid ^{3}He-A confined in a slab geometry.[1] Next we introduce key concepts in topological quantum phenomena, such as Majorana quasiparticles, odd-frequency Cooper pairing, and topological quantum phase transitions.

1. Maeno, Y., Kittaka, S., Nomura, T., Yonezawa, S., Ishida, K., J. Phys. Soc. Jpn. **81**, 011009 (2012).

O5.1 Experimental efforts to realize time-reversal invariant topological superconductors

Satoshi Sasaki, A. A. Taskin, Kouji Segawa, and Yoichi Ando

Institute of Scientific and Industrial Research, Osaka University, Japan

Recent discovery of topological insulators (TIs) characterized by topologically protected gapless surface states stimulated the search for an even more exotic state of matter, a topological superconductor (TSC). The TSC is also predicted to have a topologically protected gapless surface state consisting of massless Majorana fermions as its distinctive characteristic. Low-carrier-density semiconductors with a strong spin-orbit coupling and a Fermi surface that is centered around time-reversal-invariant momenta, such as superconducting doped TIs, are predicted to be prime candidates for TSCs.[1] Following this prediction, we studied the nature of superconductivity in doped TIs, $Cu_xBi_2Se_3$ and $Sn_{1-x}In_xTe$, by employing conductance spectroscopy.[2,3] Since $Cu_xBi_2Se_3$ is inherently inhomogeneous and it turns out to be difficult to elucidate the mechanism of superconductivity, high-quality single crystals of $Sn_{1-x}In_xTe$ with 100% superconducting volume fraction could be a promising material. I will present our latest results together with recent spectroscopy data from other groups, and summarize the current understanding of topological superconductivity in superconducting doped TI families. This work was supported by JSPS KAKENHI 24740237 and AFOSR (AOARD 124038), and done in collaboration with M. Kriener (Riken), K. Yada, M. Sato, Y. Tanaka (Nagoya), and L. Fu (MIT).

1. L. Fu and E. Berg, Phys. Rev. Lett. **105**, 097001 (2010). 2. S. Sasaki, M. Kriener, K. Segawa, K. Yada, Y. Tanaka, M. Sato, and Y. Ando Phys. Rev. Lett. **107**, 217001 (2011). 3. S. Sasaki, Z. Ren, A. A. Taskin, K. Segawa, L. Fu, and Y. Ando, Phys. Rev. Lett. **109**, 217004 (2012).

O5.2 **Topological Superfluidity of ^{3}He**

Takeshi Mizushima

Department of Physics, Okayama University, Okayama 700-8530, Japan

We here clarify the topological superfluidity of ^{3}He-A and -B under a restricted geometry. The topological superfluidity of the B-phase of ^{3}He originates from the hidden Z_2 symmetry, which ensures the existence of Majorana fermions and Ising-like anisotropy of magnetic response at the surface.[1,2] Here, we unveil the direct relation between the Majorana Ising spins and odd-frequency even-parity Cooper pairs through the topological order, where the latter is generated by the breaking of translational symmetry at the surface. In ^{3}He-A, it has been widely believed that half quantum vortices are indispensable to realize topological stable Majorana fermions. Contrary to this wisdom, we here demonstrate that integer quantum vortices can host Majorana fermions protected by the mirror Chern number.[3]

1. T. Mizushima, M. Sato, and K. Machida, Phys. Rev. Lett. **109**, 165301 (2012).
2. T. Mizushima, Phys. Rev. B **86**, 094518 (2012).
3. M. Sato, A. Yamakage, and T. Mizushima, arXiv:1305.7469.

O5.3 **New Boundary Phenomena of Liquid ^{3}He in Aerogel Contacting with Superfluid ^{3}He-B**

O. Ishikawa

Graduate School of Science, Osaka City University, Osaka, Japan

It is well understood that superfluid ^{3}He state can be described as spin triplet p-wave BCS-like condensate. Liquid ^{3}He is very pure material at low temperatures because small amount of other atoms, which behave as impurities at higher temperatures, are absorbed on the experimental cell wall. Aerogel, which is composed of thin silica strands, actually behaves as impurity in both liquid ^{3}He and superfluid ^{3}He. Impurity effect is that superfluidity of liquid ^{3}He is largely suppressed in aerogel, i.e. suppressions of both superfluid transition temperature and superfluid component. We can tune the pressure and the temperature such that there is normal liquid in aerogel and superfluid B phase just outside aerogel as bulk liquid. Near aerogel boundary, it is proposed that a proximity effect becomes significant so that p-wave Cooper pairs are destroyed by impurity scattering and s-wave Cooper pairs appear inside aerogel[1]. To conserve the antisymmetric property of Fermi particles, the frequency part of the pair wave function has odd property. We have investigated the appearance of such nobel Cooper pairs with odd frequency symmetry. Recently we observed the increase of magnetization from very near the boundary at low temperatures below T/T_c=0.2 and no increase of it far from the boundary. These observation are well explained by the theoretical calculation based on nobel Cooper pairs with odd frequency.

1.S. Higashitani *et al.*, JLTP **155**, 83-97, 2009

O5.4 The turbulent drag in superfluids

S.L. Ahlstrom[a], D.I. Bradley[a], M. Človečko[b], S.N. Fisher[a], A.M. Guénault[a], E. Guise[a], R.P. Haley[a], O. Kolosov[a], P.V.E McClintock[a], G.R. Pickett[a], M. Poole[a], R. Schanen[a], V. Tsepelin[a], and A. Woods[a]

[a]Department of Physics, Lancaster University, UK
[b]Present Address: Slovak Academy of Sciences, Kosice, Slovakia

We present studies of quantum turbulence in superfluid ^{4}He and in superfluid ^{3}He-B. Turbulence was produced using a variety of mechanical oscillators; tuning forks, vibrating wires and vibrating grids. The resonant frequencies cover a wide range from tens of hertz to tens of kilohertz. The critical velocity for turbulence nucleation in superfluid ^{4}He is consistent with a square root dependence on frequency. At high frequencies, the damping is dominated by sound emission.
At very low temperatures where the normal fluid fraction is negligible, the turbulent drag on a grid in superfluid ^{3}He-B is significantly larger than that in superfluid ^{4}He. In superfluid ^{3}He-B we believe that turbulence is generated simultaneously with quasiparticle excitations and this produces extra drag.

O5.5 Dissipation enhancement from a single reconnection event in superfluid helium

R. Hänninen

O.V. Lounasmaa Laboratory, Aalto University, Finland

We investigate a single vortex reconnection event in superfluid helium at finite temperatures using the vortex filament model [1]. The reconnection induces Kelvin waves which strongly increase energy dissipation. We evaluate the mutual friction dissipation from the reconnection and show that the dissipation power has universal form which is seen by scaling both time (measured from the reconnection event) and power by the mutual friction parameter α. This observation allows us to conclude that the Kelvin-wave cascade is not important in the energy dissipation process within the range $\alpha \gtrsim 10^{-3}$. Rather the energy is directly transferred from Kelvin waves to the normal component. Moreover, while the excited Kelvin waves greatly enhance energy dissipation, no similar change is seen in angular momentum from the reconnection event. This result is in accordance with recent measurements on the propagating vortex front [2] and might also explain the laminar decay after a sudden stop of rotation (spin-down) in ^{3}He-B [3], where pinning can be neglected. Similarly, our results confirm another earlier observation that the minimum distance between vortices scales approximately as $d = C\sqrt{|t - t_{\mathrm{rec}}|}$, both before and after the reconnection event. The prefactor C is almost temperature independent and has ten times larger value after the reconnection than before. This is due to larger curvatures induced by the reconnection event.

1. R. Hänninen, arXiv:1303.6852 (2013).
2. J.J. Hosio, *et al.*, Nat. Commun. **4**, 1614 (2013).
3. V.B. Eltsov, *et al.*, Phys. Rev. Lett. **105**, 125301 (2010).

O5.6 Finite-temperature vortex decay, core brightness and turbulence in atomic Bose-Einstein condensates

C. F. Barenghi, A. J. Allen, and N. P. Proukakis

School of Mathematics and Statistics, Newcastle University, Newcastle upon Tyne, and Joint Quantum Centre (JQC) Durham-Newcastle, United Kingdom

We study observable vortex properties in a trapped atomic Bose-Einstein condensate. Our formalism is based on a dissipative Gross-Pitaevskii equation for the condensate coupled to a semiclassical Boltzmann equation for the thermal cloud. We report results on decay rates, precession frequencies and core brightness (which can be used to experimentally determine the temperature). We also present progress towards developing experimentally accessible methods to create and characterise turbulence in atomic Bose-Einstein condensates based on altering the path of a laser stirrer.

P5.2 Exciton-polariton condensates in semiconductor microcavities

P.G. Savvidis

FORTH-IESL and Department of Materials Science and Technology, University of Crete, Heraklion, Crete, Greece

Strongly coupled semiconductor microcavities support the formation of exciton-polaritons, which can condense into macroscopically occupied quantum states or quantum liquids[1]. The investigation of such systems revealed a number of effects commonly associated with the formation of a macroscopic phase, for instance superfluid-like behaviour[2] or the appearance of quantized vortices. One of the focal points of current research regards the possibility of optically manipulating polariton condensates to realize new experiments and potential applications like all-optical polariton circuits. We develop this vision by employing a spatial light modulator to create arbitrary excitation patterns, where nonresonant excitation of polariton condensates allows us to define the potential landscape experienced by the condensates.
Novel effects regarding the interaction of multiple polaritonic quantum liquids are revealed, in particular phase-locking between freely-flowing condensates[3], the formation of vortex lattices for multiple pump spots at large separations and the transition to a trapped configuration as the pump spots are moved closer together[4]. These results enhance our ability to explore new features in macroscopic coherent systems and bring us closer to practical applications with polariton condensates such as creating all-optical coherent circuits.

1. J. Kasprzak et al., Nature 443, 409 (2006) 2. A. Amo et al., Nature 457, 291 (2009) 3. G. Tosi et al., Nature Phys. 8,190 (2012) 4. P. Cristofolini et al.,Phys. Rev. Lett. 110, 186403 (2013)

O5.7 Modified excitation spectrum and superfluidity in open-dissipative polariton condensates

M.D. Fraser[a,b], E. A. Ostrovskaya[c], S. Höfling[d], C. Schneider[d], A. Forchel[d], K. Yoshioka[b], M. Kuwata-Gonokami[b], and Y. Yamamoto[a,e]

[a]National Institute of Informatics, 2-1-2 Hitotsubashi, Chiyoda-ku, Tokyo, Japan
[b]Department of Physics, the University of Tokyo,7-3-1 Hongo Bunkyo-ku, Tokyo, Japan
[c]Nonlinear Physics Centre, Research School of Physics and Engineering, The Australian National University, Australia
[d]Technische Physik, Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany
[e]Edward L. Ginzton Laboratory, Stanford University, Stanford, California 94305-4085, USA

A unique Bose-Einstein condensate-like state can be produced in semiconductor microcavity exciton-polaritons which exists in the presence of gain and loss, raising the question as to the nature of superfluidity in such an open-dissipative setting [1,2]. We present a study of off-resonant and perturbative excitation of density waves in a stationary polariton condensate and their propagation dynamics. Via this technique we probe directly the hydrodynamics of a non-equilibrium superfluid, which exhibit dispersive density wave propagation with a supersonic group velocity resulting in the formation of dispersive shock waves. We further present direct measurements of the sound velocity in the polariton condensate.

1. Wouters, M. & Carusotto, I. “Superfluidity and Critical Velocities in Nonequilibrium Bose-Einstein Condensates”. *Phys. Rev. Lett.* **105**, 020602 (2010).
2. Keeling J. “Superfluid density of an open dissipative condensate”. *Phys. Rev. Lett.* **107**, 080402 (2011).

O5.8 Towards a stable Bose-Einstein condensate of excitons in a bulk semiconductor

K. Yoshioka, Y. Morita, K. Fukuoka, and M. Kuwata-Gonokami

Department of Physics, and Photon Science Center, The University of Tokyo, Japan

Realization of macroscopic quantum coherence such as Bose-Einstein condensation (BEC) in an ensemble of excitons in a semiconductor, has been a central issue in solid-state spectroscopy for more than forty years. Condensation of long-lived excitons in a bulk semiconductor that are decoupled from photons is of particular interest, since such excitons behave as purely matter-like quasiparticles and the condensate would show novel characteristics. Here we explain why it has been difficult to meet the BEC criteria above 2 K, and we present a series of experimental results where (1) we observed the transition to an exciton BEC in a three-dimensional trap at sub-Kelvin temperatures[1], and (2) realized a record-breaking low exciton temperature to stabilize the condensate by using a dilution refrigerator.

1. K. Yoshioka, E. Chae, and M. Kuwata-Gonokami, Nature Commun. 2, 328 (2011).

O5.9 Ultrasound Measurement in Solid Helium in a Torsional Oscillator

I. Iwasa[a], J.M. Goodkind[b], and H. Kojima[c]

[a]Department of Mathematics and Physics, Kanagawa University, Kanagawa, Japan[b]Physics Department, UCSD, California, USA
[c]Serin Physics Laboratory, Rutgers University, New Jersey, USA

The anomalous increase in the torsional oscillator (TO) period containing solid ^{4}He has been interpreted[1] in terms of dislocation line motion. To search for correlation between dislocations and the TO anomaly, simultaneous measurements of longitudinal ultrasound at 10 MHz and torsional oscillation were performed[2]. Polycrystalline solid ^{4}He samples were grown by the blocked capillary method from commercial ^{4}He gas (^{3}He concentration 0.3 ppm) and from a mixture gas with ^{3}He concentration of 20 ppm. The temperature dependence of sound velocity above 100 mK in 0.3 ppm samples was found to be similar to that of single crystals of ^{4}He. The average network pinning length (2.2 μm) and the effective dislocation density (1.1×10^9m^{-2}) were obtained from the ultrasound data. At temperatures below 100 mK, both the sound velocity and attenuation depended on the TO and sound drive levels and thermal history. This is the temperature range where the anomaly of the simultaneously-measured TO period appears. These effects on the sound velocity and attenuation will be discussed in terms of pinning of dislocations by ^{3}He impurities.

1. I. Iwasa, J. Low Temp. Phys, **171**, 30 (2013).
2. B. Hein, J.M. Goodkind, I. Iwasa and H. Kojima, J. Low Temp. Phys. **171**, 322 (2013).

O5.10 First-sound Measurements of Liquid ^{4}He near T$_\lambda$ in Microfluidic Devices

X. Rojas, Y. Yang, A. Duh, and J. P. Davis

Department of Physics, University of Alberta, Edmonton AB, Canada

We present the first measurements of a new type of apparatus to probe the properties of quantum fluids in restricted geometries. We have confined liquid ^{4}He within microfluidic devices formed from borosilicate glass, in which one dimension is restricted to nanometer or micron scales. Nanofabrication techniques allow us to obtain fine control over the size and roughness of the surfaces of the resulting cavity [1]. Using an acoustic Fabry-Pérot technique we measure the first-sound of liquid ^{4}He confined within these cavities, which is a sensitive probe of the superfluid state. Piezoelectric drive and receiver transducers are bound onto each side of the device in order to measure the acoustic signal transmitted through the resonant cavity with a high-frequency lock in amplifier. We show preliminary measurements probing finite size effects near T$_\lambda$ in confined liquid ^{4}He using this technique. This experiment could also be extended to liquid ^{3}He, in order to obtain a direct measurement of transverse sound in the normal state, or to verify the theoretical prediction of a new superfluid phase that breaks the translational symmetry [2].

[1] Microfluidic and Nanofluidic Cavities for Quantum Fluids Experiments, A. Duh, A. Suhel, B.D. Hauer, R. Saeedi, P.H. Kim, T.S. Biswas and J.P. Davis, J. Low Temp. Phys. **168**, 31 (2012).

[2] Crystalline Order in Superfluid ^{3}He Films, A. B. Vorontsov and J. A. Sauls, PRL **98**, 045301 (2007).

O5.11 Discontinuous Growth of Solid ^{4}He From the Superfluid Phase on Graphene Nanoplatelets

A. Koga[a], Y. Shibayama[b], and K. Shirahama[a]

[a]Dept. of Phys., Keio University, Yokohama, Japan
[b]Present Address: Appl. Mat. Sci. Research Unit, Muroran Inst. of Tech., Muroran, Japan

Research has shown interesting layer-by-layer growth of solid ^{4}He on graphite surfaces, even well below the bulk freezing pressure[1−3]. However, the exfoliated graphite samples (Grafoil) used in these studies consist of nanometer-sized platelets, on which the growth dynamics might be greatly influenced by the finite size and unideal substrate structure. We present a torsional oscillator study for the growth of solid ^{4}He from the superfluid phase on commercially available graphene nanoplatelets with average diameters of a few μm and thickness 6 nm. Measurements from 1.65 K to 0.1 K have revealed that below 1.2 K, the growth of one solid layer occurs as a series of discontinuous steps. Some of the discontinuities are preceded by melting of up to one solid layer.

1. M.J. McKenna, T.P. Brosius, and J.D. Maynard, Phys. Rev. Lett. **69**, 3346 (1992).
2. V. Gridin, J. Adler, Y. Eckstein, and E. Polturak, Phys. Rev. Lett. **53**, 802 (1984).
3. A.M. Koga, Y. Shibayama, K. Shirahama, J. Low. Temp. Phys. **166**, 257 (2012).

Poster Presentations: Monday August 5th

PS5.1 Fermi and Bose gases within Multitubes

P. Salas and M. A. Solís

Instituto de Física, Universidad Nacional Autónoma de México, México.

We report the thermodynamic properties of Boson and Fermi ideal gases immersed in periodic structures such as penetrable multilayers [1] or multitubes [2] simulated by one (planes) or two perpendicular (tubes) external Dirac comb potentials, while the particles are allowed to move freely in the remaining directions. Although the bosonic chemical potential is a constant for $T < T_c$, a non decreasing with temperature anomalous behavior of the fermionic chemical potential is confirmed [3] and monitored as the structure goes from 2D to 1D when the wall impenetrability overcomes a critical value. In the specific heat curves dimensional crossovers are very noticeable at high temperatures for both gases, where the system behavior goes from 3D to 2D and latter to 1D as the wall impenetrability is increased.

1. P. Salas, F. J. Sevilla, M. Fortes, M. de Llano, A. Camacho, and M. A. Solís, *"Dimensional crossover of a boson gas in multilayers"*, Phy. Rev. A **82**, 033632 (2010).

2. P. Salas, F. J. Sevilla, and M. A. Solís, *"Boson gas in a periodic array of tubes"*, J. of Low Temp. Phys. **168**, 258 (2012).

3. M. Grether, M. Fortes, M. de Llano, J. L. del Río, F. J. Sevilla, M. A. Solís, and A. A. Valladares, Eur. Phys. J. D **23**, 117 (2003).

PS5.2 BEC and dimensional crossover in a boson gas within multi-slabs

M.A. Solís[a] and O. A. Rodríguez[b]

[a]Instituto de Física, Universidad Nacional Autónoma de México, MEXICO

[b]Posgrado en Ciencias Físicas, Universidad Nacional Autónoma de México, MEXICO

For an ideal Bose-gas within a multi-slabs periodic structure, we report a dimensional crossover and discuss whether a BEC transition at $T_c \neq 0$ disappears or not.

The multi-slabs structure is generated via a Kronig-Penney potential perpendicular to the slabs of width b and separated by a distance a. The ability of the particles to jump between adjacent slabs is determined by the hight of the potential barrier and the separation a between them. Contrary to what happens in the boson gas inside a zero-width multilayers case [1], where the critical temperature diminishes and goes up again as a function of the wall separation, here the T_c decreases continuously as the potential barrier height and the cell size $a + b$ increase. We plot the surface $T_c = 10^{-6}$ showing two prominent regions in the parameters space, which suggest a phase transition BEC-NOBEC at $T \neq 0$. The specific heat shows a crossover from 3D to 2D when the height of the potential or the barrier width increase, in addition to the well known peak related to the Bose-Einstein condensation.

1. P. Salas, F.J. Sevilla, M. Fortes, M. de Llano, A. Camacho and M.A. Solis, (2010). "Dimensional crossover of a boson gas in multilayers". Phys. Rev. A **82**, 033632.

PS5.3 Possible Phase Diagram of Imperfect Bose Liquid in Nanoporous Glass

Yu Ogata, Hiroyoshi Horikawa, and Ryusuke Ikeda

Department of Physics, Kyoto University, Japan

Experimentally, a quantum phase diagram suggestive of a normal liquid ground state or a quantum critical point of the superfluid transition has been argued for the dense ^{4}He confined in nanoporous media[1] . However, the argument on a normal bose liquid at zero temperature should be reconsidered. Here we study effects of quenched disorder stemming from the structure of the porous material on the bose superfluid transition depressed by the quantum phase fluctuation and find that, reflecting the presence of the bose glass[2] at zero temperature but at higher pressures, the superfluid region is enhanced at low enough temperatures. Further, we also consider effects of dilute ^{3}He atoms on the bose superfluid transition, and, even in this case, it is found that, at low enough temperatures, the ^{3}He gas enhances the bose superfluidity.

1. K. Yamamoto, Y. Shibayama, and K. Shirahama, Phys. Rev. Lett. **100**, 195301 (2008).
2. M. P. A. Fisher et al., Phys. Rev. B **40**, 546 (1989).

PS5.4 Exact Analysis of a One-Dimensional Weakly Repulsive Bose-Fermi Mixture

Toshiaki Kaminaka[a], Jun Sato[b], and Tetsuro Nikuni[a]

[a]Department of Physics, Faculty of Science, Tokyo University of Science, Japan

[b]Department of Physics, Graduate School of Humanities and Sciences, Ochanomizu University, Japan

We study one-dimensional system of Bose-Fermi mixture with repulsive δ-function interactions using the nested Bethe ansatz method [1,2]. This system is integrable when the masses of bonsons and fermions are equal and the interactions between Bose-Bose and Bose-Fermi particles are equal. By use of the power series expansion method [3], the Surtherland integral equation [4] describing the ground state properties is solved analytically in the weak coupling regime. Physical quantities such as the ground state energy, sound velocity, and the chemical potential are explicitly expressed in terms of a dimensionless parameter $\gamma = c/D$ and boson fraction $\alpha = N_b/N$, where c is the interaction strength, D is the number density, N_b is the number of bosons, and N is the total number of particles.

1. H. A. Bethe, Z. Phys. **71**, 205 (1931).
2. C. N. Yang, Phys. Rev. Lett.**19**,1312 (1967).
3. M. Wadati, J. Phys. Soc. Jpn. **71** 2657 (2002).
4. B. Sutherland, Phys. Rev. B **12**, 3795-3805 (1975)

PS5.5 ^{3}He Monolayers on Graphite in Ferromagnetic Regime: Cluster Size Effect

K. A. Chishko, T. N. Antsygina, I. I. Poltavsky, and M. I. Poltavskaya

B.Verkin Institute for Low Temperature Physics and Engineering, Kharkov, Ukraine

The second solid ^{3}He monolayer on graphite provides an excellent example of a nearly perfect 1/2 - spin nuclear magnet on a triangular lattice. As the total coverage increases, the exchange J in the second layer evaluates from antiferromagnetic ($J > 0$) up to ferromagnetic ($J < 0$) with maximum of susceptibility just at third layer completion. The experiments on magnetization show that ^{3}He layers behave like a complex of magnetic nanoclusters whose average size varies with total coverage of the ^{3}He multilayered system. We investigate the magnetization of 2D ^{3}He monolayer theoretically within a ferromagnetic Heisenberg model (HFM) in an external magnetic field. We employ an analytical approach based on a second-order two-time Green function formalism with a new decoupling scheme that describes properly the HFM thermodynamics for both infinite and finite-sized spin systems in the whole temperature range at arbitrary fields h. In particular, the proposed method improves significantly the description of the 2D HFM at $h < T < J$ (J is an exchange constant) and ultralow magnetic fields $h/J \ll 1$, where the measurements for solid ^{3}He monolayers are usually made. The obtained results are used to give a consistent interpretation to a great number of known from literature experimental data on magnetization of the second solid ^{3}He monolayer in the ferromagnetic regime. It is proved that at dense coverages $\rho \geq 0.22\text{Å}^{-2}$ the pure Heisenberg behavior of 2D solid ^{3}He occurs, and the theory is in excellent agreement with the experimental data at all temperatures. The coverage dependences of the exchange constant, saturation magnetization M_{sat}, and average cluster size N are analyzed in detail. The exchange constant is found to display nonmonotonic behavior with increase in coverage, whereas M_{sat} as well as N continuously grow tending to their limiting values. Magnetization of 2D ^{3}He-^{4}He solid solutions has been also discussed.

PS5.6 Anisotropy of the Adiabatic Relaxation Time of Adsorbed ^{3}He Monolayer

K. Matsumoto

Department of Applied Sciences, Muroran Institute of Technology, Muroran, 050-8585, Japan

We investigate the anisotropy of the adiabatic relaxation time T_2' of adsorbed monolayer solid ^{3}He. We calculate T_2' based on the phenomenological Heisenberg Hamiltonian with the nearest-neighbor (J_1) and the next nearest-neighbor (J_2) exchange interactions. Furthermore, the four particle exchange (K) in the two-dimensional triangular plane is also incorporated. To calculate T_2', it is necessary to compute the second and the fourth moments of the resonance line M_2 and M_4. To obtain them, we can use the formulas published in a previous study.[1] In the results, we observe no significant difference between the nearest-neighbor Heisenberg model and the four particle spin interaction models. A comparison of the present results and the experimental data is briefly discussed.

1. K.Matsumoto, Eur. Phys. J. B (2013) 86, 37

PS5.7 NMR study on motional state of helium film adsorbed in nanochannels of FSM silicate

T. Matsushita, R. Kawai, K. Kurebayashi, D. Tokioka, M. Hieda, and N. Wada

Department of Physics, Nagoya University, Nagoya 464-8602, Japan

Nondegenerate ^{4}He and ^{3}He films adsorbed on disordered surface such as in nanoporous materials have shown quite similar heat capacities, up to coverages a little above the first-layer completion n_1, where the quantum-fluid layer appears. Those heat capacities show a steep decrease below a temperature T_{L}, where mobile adatoms on the wall are considered to be localized.

In this study, we have studied the motional state of ^{3}He film adsorbed in 2.4 nm channels of FSM silicate. Using pulsed-NMR at 3.3 MHz, the spin-lattice and spin-spin relaxation times T_1, T_2 of ^{3}He film were systematically measured down to 0.54 K, lower than those in the previously reported experiment[1]. Temperature dependences of relaxation times are attempted to be analyzed in terms of the dipolar relaxation such as Bloembergen-Purcell-Pound (BPP) model, and compared with the phase diagram determined by the heat-capacity measurement. In submonolayer films, the temperature of T_1-minimum, which implies the dipolar correlation time τ_{c} nearly equals to the NMR period, lowers almost linearly to the film coverage, indicating that adatoms become more mobile in thicker film. In addition, at the temperature a little below the T_1-minimum, an inflection was always found in the T dependence of T_2. This feature is probably characteristic of film in 1D nanochannels, which has not been observed in films adsorbed on flat substrates or 3D nanopores. Below 2 K, steep increase of T_1 dependent on coverage was observed, which agrees with localization of adatoms below T_{L}, suggested by the heat capacities.

1. T. Matsushita, A. Kuze, R. Kawai, M. Hieda, and N. Wada, J. Low Temp. Phys. **171**, 657 (2013).

PS5.8 Three-Dimensional Boltzmann Gas and Possible Singlet Bound State of ^{3}He Film Formed in Nanopore of HMM-2

N. Wada[a], D. Tokioka[a], M. Kuno[a], R. Toda[b], M. Hieda[a], and T. Matsushita[a]

[a]Department of Physics, Nagoya University, Nagoya 464-8602, Japan

[b]Cryogenic Research Center, The University of Tokyo, Yayoi, Tokyo 113-0032, Japan

We have realized a new gas state of ^{3}He film adsorbed on ^{4}He-preplated nanopore wall of HMM-2 whose pores 2.7 nm in mean diameter regularly connect in three-dimension (3D) with a period 5.5 nm. In the case of a thick ^{4}He-preplating of 1.7 atomic layers, specific heat C/n_3 of a dilute ^{3}He film was observed to be 1.37($\pm$0.10) R, where R is the gas constant, down to the lowest temperature (28 mK) measured. The constant specific heat indicates the Boltzmann gas state of the ^{3}He film of which C/n_3 is much larger than R of the 2D gas and close to 1.5 R of the 3D ideal gas. For a ^{4}He-preplating of 1.2 layers, C/n_3 of the ^{3}He film was observed to be 1.45($\pm$0.10) R down to 0.6 K, indicating the ideal 3D Boltzmann gas. With decreasing the temperature, C/n_3 shows a maximum of $\approx 3.2\,R$ at 0.17 K, followed by a drop to be almost zero at the lowest temperature 28 mK. The result suggests a singlet bound state with a gap energy about 0.2 K. Large binding energy of a singlet dimer has been calculated for ^{3}He atoms adsorbed in a nanopore[1]. The calculated binding energy is strongly changed by the adsorption potential on the nanopore wall.

1. K. Yamashita, and D.S. Hirashima, J. Phys. Soc. Jpn. **80**, 114602 (2011).

PS5.9 Submonolayer Superfluidity of ^{4}He Films on Planar Gold

M. Hieda, H. Yamaguchi, H. Tanaka, T. Matsushita, and N. Wada

Department of Physics, Nagoya University, Nagoya, Japan

To explore the nature of two-dimensional (2D) superfluidity arising from the Kosterlitz-Thouless (KT) transition, ^{4}He films have long been studied using various techniques. Further studies on pure 2D system are still required: In the previous reports[1,2] for the submonolayer films (the KT transition temperature $T_{\mathrm{KT}} < 1$ K) on Mylar, the dynamic KT theory incompletely succeeded in quantitatively agreement with temperature dependence of the superfluid density ρ_{s} and the dissipation ΔQ^{-1}. Thus we have studied submonolayer superfluidity of ^{4}He films on planar gold substrate using a quartz crystal microbalance (QCM). In this presentation, we report new data at various submonolayer coverages ($0.1 < T_{\mathrm{KT}} < 0.8$ K), which was measured at 60 MHz with a long term stability improved by temperature control of coaxial cables placed at room temperature. In low temperature region $T/T_{\mathrm{KT}} < 0.7$ at all measured coverages, T^3 dependence of 2D phonon in normal fluid density was observed. By the adoption of 2D phonon as the background superfluid density, it was also successful to explain the entire region of temperature dependence of ρ_{s} and ΔQ^{-1} by the dynamic KT theory.

1. G. Agnolet, D. F. McQueeney, and J. D. Reppy, Phys. Rev. B 39, 8934 (1989).
2. H. Yano, T. Joha, and N. Wada, Phys. Rev. B 60, 543 (1999).

PS5.10 Helium-4 crossover from a 3d superfluid to a 1d Luttinger liquid in a nanopore

B. Kulchytskyy[a], G. Gervais[a], and A. Del Maestro[b]

[a]Department of Physics, McGill University, Montreal, H3A 2T8, Canada

[b]Department of Physics, University of Vermont, Burlington, VT 05405, USA

Quantum Monte Carlo studies of helium-4 at low temperatures show that when it is confined to flow in narrow cylindrical pores with nanometer radii, it tends to form concentric shells around a possible inner core. The latter potentially represents an experimental playground for exploring the implications of Luttinger liquid theory for one dimensional quantum fluids. We have performed large scale numerical simulations investigating the crossover from a bulk three dimensional superfluid to a one dimensional Luttinger liquid as the nanopore radius is reduced. Measurements of heat capacity and entropy provide new insights in the thermodynamic signatures of the dimensional crossover of strongly interacting confined fluids.

PS5.11 Frequency-independent 1D superfluid response in ^{4}He film adsorbed in nanochannels

T. Endoh, M. Okamoto, T. Matsushita, M. Hieda, and N. Wada

Department of Physics, Nagoya University, Nagoya 464-8602, Japan

Recently one-dimensional (1D) superfluid responses have been observed for ^{4}He film (nanotube) adsorbed in nanochannels, essentially in the 1D state where elementary excitations observable in the specific heats are only 1D phonons along the channel axis[1]. These responses observed by torsional oscillators are characterized by a gradual increase of the superfluid density and accompanying broad dissipation peak, which completely differ from superfluid onsets observed in ^{4}He systems in higher dimensions. Recent theoretical works have shown that 1D superfluid can be observed in finite systems with respect to the length or/and frequency.

In this study, we have investigated the oscillation-frequency dependence of the 1D superfluid onset for ^{4}He film adsorbed in 2.4 nm channels of FSM silicate, which is implied by existence of a broad dissipation peak observed at the onset. The frequency dependence was studied using two torsional oscillators with different resonance frequencies 1 and 2 kHz simultaneously, as well as the amplitude dependences. Unexpectedly, any detectable differences in the onset temperature have not been observed between two frequencies, which suggests that the observed onset corresponds to the 1D superfluid density in the system with a finite length, rather than the superfluid response determined by the finite oscillating frequency.

1. N. Wada, Y. Minato, T. Matsushita, M. Hieda, J. Low Temp. Phys. **162**, 549 (2011); N. Wada, M. Hieda, R. Toda, and T. Matsushita, to be published in Low Temp. Phys. [Fiz. Nizk. Temp.].

PS5.12 Highly mobile metastable state of ^{4}He thin layers above the KT transition temperature

K. Okamura[a], K. Noda[a], J. Taniguchi[a], M. Suzuki[a], M. Hieda[a], and T. Minoguchi[c]

[a]Department of Engineering Science, University of Electro-Communications, Japan

[b]Department of Physics, Nagoya University, Japan

[c]Institute of Physics, University of Tokyo, Japan

We have observed mass decoupling of ^{4}He layers on an exfoliated single-crystalline graphite by means of quartz crystal microbalance (QCM) using a 32 kHz tuning fork, and found highly mobile metastable state above the KT transition temperature T_{KT}. After decreasing an oscillation amplitude, mobile ^{4}He layers stick fast to the substrate with a finite relaxation time $\tau(T)$. It was found that $\tau(T)$ obeys the Arrhenius law in the high temperature region (I). In contrast, it decreases rapidly with decreasing temperature in the low temperature region (II).[1] In this report, we show that in the temperature region II, $\tau(T)$ collapses into a single curve if scaled by T_{KT}. The collapse can be explained by the mechanism that a local superfluid ordering contributes to the annihilation of dislocation kink-antikink pairs of solid ^{4}He layers.

1. K. Noda et al., *J. Low Temp. Phys.* **171** 638 (2013).

PS5.13 Competition between superfluid overlayer and mobile solid layer of ^{3}He-^{4}He mixture films on porous gold

J. Taniguchi[a], T. Mouri[a], M. Suzuki[a], M. Hieda[b], and T. Minoguchi[c]

[a]Department of Engineering Science, University of Electro-Communications, Japan

[b]Department of Physics, Nagoya University, Japan

[c]Institute of Physics, Tokyo University, Japan

In the previous QCM measurements for ^{4}He films adsorbed on porous gold, we have observed a competition between superfluidity and slippage: In relative low areal densities, the resonance frequency increases gradually below a certain temperature T_S due to the slippage of solid layer, while the superfluid onset T_C is observed in high areal densities. In the crossover region, the slippage below T_S is suddenly suppressed at a certain temperature T_D, which is just below T_C. As an origin of this sudden suppression, the hardening of a new sound mode has been suggested, where a superfluid component oscillates with a normal component bound to dislocations in solid layer in an out-of-phase way.[1] To change the amount of normal component, we introduced a small amount of ^{3}He onto ^{4}He films, and studied the competition as a function of ^{3}He areal density ρ_3. As ρ_3 is increased, T_C is monotonically suppressed. On the other hand, T_D increases in the low ρ_3 region, and then turns over to decrease in parallel to T_C. We will discuss the ρ_3 dependence based on the new sound mode.

1. T. Minoguchi, J. Phys.: Conf. Ser. **150** 032060 (2009).

PS5.14 ^{3}He impurity effect on the superfluidity for liquid ^{4}He confined in 1D nanoporous medium FSM16

Kenta Demura, Junko Taniguchi, and Masaru Suzuki

Department of Engeineering Science, University of Electro-Communications, Japan

We have studied the superfluidity of liquid ^{4}He confined in FSM16. It was found that the superfluid response depends on measuring frequency, which indicates a dynamical phenomenon.[1] We report here the superfluid response when a small amount of ^{3}He is added. Three samples of 0.0, 2.0, 4.0 atom % were measured at two frequencies of 2000 and 500 Hz by means of double torsional oscillator. As ^{3}He concentration was increased, the superfluid response shifted to lower temperature than pure liquid ^{4}He. Concerning the frequency dependence, the response at 500 Hz was suppressed by several tens mK from 2000 Hz for 2.0 and 4.0 % ^{3}He.

1. J. Taniguchi, K. Demura, M. Suzuki, *J. Low Temp. Phys.*, **171**, 644-649 (2013).

PS5.15 Reentrant Solidification of First Layer of ^{4}He Film on Graphite

Masashi Morishita

Faculty of Pure and Applied Sciences, University of Tsukuba, Japan

According to many experimental observations and theoretical calculations, the first adsorbed layer of ^{3}He films on graphite surfaces is believed to solidify from the fluid phase to the $\sqrt{3}\times\sqrt{3}$ phase with increasing areal density at low temperatures, then forming some adsorption structures, and finally resulting in the incommensurate solid phase. A plausible adsorption structural phase diagram has been proposed.[1] ^{4}He films are also thought to exhibit a similar evolution. However, there is almost no experimental observation to discuss the evolution of the adsorption structure of ^{4}He films except the results of heat-capacity measurements at high temperatures.

I present the results of heat-capacity measurements of dilute ^{3}He-^{4}He mixture films; these measurements serve as a potential method to clarify the nature of a ^{4}He film. Similar measurements were performed for the second adsorbed layer and have revealed that the second adsorbed layer of ^{4}He does not solidify into the so-called "4/7 phase."[2] The results of this work strongly suggest that the first adsorbed layer of ^{4}He films solidifies only for a very narrow range of areal density near that of the $\sqrt{3}\times\sqrt{3}$ phase and also at higher areal densities. These behaviors are contrary to the expected evolution.

1. M. Morishita, *J. Phys. Chem. Solid* **66**, 1425 (2005) and references therein.
2. M. Morishita, *J. Low Temp. Phys.* **171**, 664 (2013).

PS5.16 SQUID-NMR studies of ^{3}He Films on Graphite in the Microkelvin Temperature Range

F. Arnold, B. Yager, J. Nyéki, B. Cowan, and J. Saunders

Department of Physics, Royal Holloway University of London, Egham, TW20 0EX, United Kingdom

We report preliminary measurements of the spin-dynamics of ^{3}He films adsorbed on graphite at temperatures in the range 200 μK to 300 mK. These films provide a model system for the study of both strongly correlated two-dimensional Fermi-systems and the frustrated magnetism of a two-dimensional $S = 1/2$ solid on a triangular lattice. Pulsed SQUID-NMR techniques have been used to investigate the nuclear spin susceptibility, frequency shift and spin-spin relaxation time.

A two layer ^{3}He film consisting of a paramagnetic first layer and strongly correlated Fermi fluid second layer, is observed to exhibit two component free induction decays. Analysis in terms of a model for coupled spin-relaxation provides evidence for slow interchange between the two subsystems. On increasing the coverage the second layer is believed to form a 4/7 or 7/12 triangular superlattice, with a gapless quantum spin-liquid state. Our experiment allows the study of the spin dynamics of this $S = 1/2$ quantum spin-liquid on a triangular lattice, and by finely tuning the helium-3 coverage, the influence of hole-doping.

PS5.17 Mobility of 2D Electrons on pure ^{4}He and ^{3}He–^{4}He dilute solution

Hideki Yayama[a] and Yosuke Yatsuyama[b]

[a]Department of Physics, Faculty of Arts and Science, Kyushu University, Fukuoka 812-8581, Japan

[b]Deaprtment of Physics, Graduate School of Sciences, Kyushu University, Fukuoka 812-8581, Japan

Mobilitiy of 2D electrons on pure ^{4}He and on 0.5% solution of ^{3}He in ^{4}He was investigated for different electron densities in the temperature range 0.12 to 1.3 K. The electrons in the same electron density showed the same transition temperature from liquid state to Wigner crystal state on both pure ^{4}He and the solution. Above $\sim$0.4 K where the gas-scattering was predominant, the electrons showed a smaller mobility on the solution than on the pure ^{4}He due to the electron collision with ^{3}He atoms which has a higher vapor pressure. Below $\sim$0.4 K where the ripplon-scattering was predominant, the mobility stayed almost constant on the pure ^{4}He, while it increased a little with decreasing temperature on the solution. This difference was caused by the change in ripplon spectrum with a little amount of ^{3}He added in ^{4}He. The change in ripplon spectrum came from the change in surface tension of the liquid with decreasing temperature. The present result was regarded as a detection of the 2D ^{3}He layer at the surface of ^{3}He–^{4}He dilute solution which is theoretically predicted by Andreev.

PS5.18 Fabrication of graphite substrates to study two dimensional helium films

O. Zadorozhko and E. Kim

Center for Supersolid and Quantum Matter Research, KAIST, Daejeon 305-701, Republic of Korea

The homogeneity of a substrate is important to investigate the quantum properties of helium films at low temperatures. For instance, the surface heterogeneities in Grafoil substrate induces the broadening of heat capacity near the density of the $\sqrt{3}$ x $\sqrt{3}$ [1]. The heat capacity of helium films adsorbed on a ZYX substrate shows much sharper transition at the critical density. We will report preliminary study on making homogeneous graphite substrate with large surface area and well defined orientation. A highly oriented pyrolitic graphite(HOPG) is used as a base material. HOPG is intercalated by potassium with a two-zone vapor transport technique and then exfoliated by heating slowly the intercalated graphite to 1000 °C.

1. S. Nakamura et al. JLTP v171, p711 (2013).

PS5.19 Nonlinear Transport of the Wigner Crystal in a Confinement Geometry

N.R. Beysengulov[a,b], D.G. Rees[c,d], H. Ikegami[a,d], D.A. Tayurskii[b], and K. Kono[a,d]

[a]Low Temperature Physics Laboratory, RIKEN, Wako-shi, Japan

[b]Institute of Physics, Kazan Federal University, Kazan, Russia

[c]NCTU-RIKEN Joint Research Laboratory, National Chiao Tung University, Hsinchu, Taiwan

[d]RIKEN Center for Emergent Matter Science (CEMS), Wako-shi, Japan

We investigate the nonlinear transport of a quasi-one-dimensional (Q1D) electron system formed on the ultra-clean surface of superfluid ^{4}He, in a microchannel 10 μm-wide and 100 μm-long. By applying voltages to electrodes at the microchannel edges and beneath the helium surface, the confinement potential, and therefore electron density, can be controlled. A detailed finite-element analysis of the microdevice was performed in order to calculate the confinement potential. This electrostatic model was found to explain many features of the electron transport through the microchannel. Under certain conditions, we were able to observe reentrant melting of the Q1D Wigner crystal as the number of electron rows formed in the microchannel varied. The number of electron rows observed experimentally agreed well with the number predicted by the electrostatic model. The nonlinear response of the system to an increased driving force was also investigated. It was found that the sliding of the Q1D Wigner crystal on the helium surface, which occurs due to the decoupling of the electrons from the underlying dimple lattice (deformation of the helium surface), depends on both the positional order of electron rows and temperature of the electron system. With increasing driving fields, the sliding transition occurs for higher electron densities in the microchannel, and the features of the sliding transition become sharper. In addition, the sliding of the Wigner crystal loses its dependence on the reentrant melting.

PS5.20 Complex-valued fractional statistics for D-dimensional harmonic oscillators

A. Rovenchak

Department for Theoretical Physics, Ivan Franko National University of Lviv, Ukraine

Properties of a system of harmonic oscillators in a space having the dimension $1 \le D \le 2$ are studied. The oscillators obey the fractional statistics of Polychronakos [1] with the parameter being a complex number on the unit circle [2]. Heat capacity of such a system is calculated and the peculiarities of its behavior are studied in the bosonic limit. A possible interpretation of the complex parameter is to consider a Bose-system with a weak dissipative part in the spectrum of elementary excitations [2]. The nature of the observed phase transitions is clarified. Both numerical and analytical estimates for the critical temperature are made depending on the number of particles, space dimensionality, and statistics parameter.

The obtained results can be easily transferred from oscillators to systems of free particles in dimensions $2 \le D \le 4$ due to similarities of the density-of-state functions. Indeed, for the linear spectrum of harmonic oscillators the density of states is $g(\varepsilon) \propto \varepsilon^{D-1}$ while for free particles $g(\varepsilon) \propto \varepsilon^{D/2-1}$. Therefore, the obtained approach can be used to study the properties of a continuous transition between planar and bulk geometries.

1. A. P. Polychronakos, Phys. Lett. B **365**, 202 (1996).
2. A. Rovenchak, J. Phys.: Conf. Ser. **400**, 012064 (2012).

PS5.21 Improving the ballistic ac conductivity through quantum resonance in nanowires

V. Sanchez[a] and C. Wang[b]

[a]Departamento de Fisica, Facultad de Ciencias, Universidad Nacional Autonoma de Mexico, Mexico

[b]Instituto de Investigaciones en Materiales, Universidad Nacional Autonoma de Mexico, Mexico

Based on the Kubo-Greenwood formula, a renormalization plus convolution method[1] is developed to investigate the frequency-dependent electrical conductivity of quasiperiodic systems. This method combines the convolution theorem with the real-space renormalization technique, being able to address multidimensional systems with 10^{24} atoms. In this work, an analytical evaluation of the Kubo-Greenwood formula is presented for the ballistic ac conductivity in periodic chains. But for quasiperiodic Fibonacci lattices connected to two semi-infinite periodic leads, the electrical conductivity is calculated by using the renormalization method and the results show that at several frequencies their ac conductivities could be larger than the ballistic ones. This fact might be related to the resonant scattering process in quasiperiodic systems. Moreover, calculations made in segmented Fibonacci nanowires[2] reveal that this improvement to the ballistic ac conductivity via quasiperiodicity is still present in multidimensional systems. Finally, an analysis of these resonant ac transport modes at low temperature is also presented.

1. Sanchez V. and Wang C. (2004) Phys. Rev. B 70, 144207.
2. Wang C., Salazar F. and Sanchez V. (2008) Nano Lett. 8, 4205.

PS5.22 Surface electron transport over structured silicon substrate, limited by ripplon and gas scattering

A.V. Smorodin, V.A. Nikolaenko, and S.S. Sokolov

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

In our work quasi-zero-dimensional (Q0D) system of surface electrons (SE) is realized at helium temperature. The system is formed by electrons over superfluid helium placed in cylindrical macropores of a structured silicon substrate. It is shown that the pressing electric field, normal to the electron layer can change essentially the potential well for electrons, depending on curvature of the liquid surface. Conductivity of surface electrons with densities 10^6 to 10^8 cm^{-2} is measured at temperatures $T = 0.5 - 3.0$ K and pressing fields up to 10^3 V/cm. The electron transport along the substrate depends strongly on curvature radius of liquid surface in macropores. If the curvature radius is high and, thereafter the helium film is thin, the electron conductivity has activation nature, typical for the hopping processes. With decreasing the curvature radius the temperature dependence of conductivity becomes smooth. The measurement in gas region (temperature 2-3 K) show that one observes a formation of polaron state of the surface electrons. Also we observe dependence of conductivity vs temperature for 2D and Q1D SE system in gas scattering region and compare with the data for Q0D. It was found that formation of a polaron state for Q0D systems occurs at lower temperature. We also propose theoretical explanation the observed phenomena.

PS5.23 Dispersion of Collective Modes in Electron Quantum Wire Over Liquid Helium in a Magnetic Field

I. A. Degtiarov, T. N. Antsygina, and S. S. Sokolov

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

We consider the dispersion of plasma oscillations in non-degenerate quasi-one-dimensional electron system basing on surface electron system over liquid helium. We applied the random phase approximation (RPA) formalism to two-subband model in presence of magnetic field and obtained the response functions basing on binomial approach to electron wave function. The validity of binomial approach is estimated in wide range of magnetic fields to be better than 10 - 15 %. The dispersion laws of RPA are compared with those obtained previously in quasi-crystalline approximation both without and in presence of magnetic field. The dispersions in both approaches are similar qualitatively especially in long wavelength limit though quantitative difference is available at high enough wave numbers close to the upper edge for first Brillouin zone. The difference between the results of two approaches is especially expressed for transversal mode where the depolarization shift increases appreciably the threshold frequency in optical transversal mode in comparison with that in quasi-crystalline approach.

PS5.24 Transport in Fermi Liquids Confined by Rough Walls

Priya Sharma

Theoretical Sciences Unit, Jawaharlal Nehru Centre for Advanced Scientific Research, Jakkur, Bangalore 560064, India.

I present theoretical calculations of transport coefficients of Fermi liquid ^{3}He confined to a slab of thickness of order $\sim$ 100nm. The effect of the roughness of the confining surfaces is included directly in terms of the surface roughness power spectrum which may be determined experimentally. Transport at low temperatures is limited by scattering off rough surfaces and evolves into the known high-temperature limit in bulk through an anomalous regime in which both inelastic quasiparticle scattering and elastic scattering off the rough surface coexist. I show preliminary calculations for the coefficients of thermal conductivity and viscosity. These studies are applicable in the context of electrical transport in metal nanowires as well as experiments that probe the superfluid phase diagram of liquid ^{3}He in a slab geometry.

PS5.25 Superconducting Fluctuations and Phase Slips in Niobium-Nitride Nanowires on Suspended Carbon Nanotubes

S. Moriyama[a], T. Hashimoto[b], Y. Morita[c], K. Masuda[b], N. Miki[d], and H. Maki[b]

[a]International Center for Materials Architectonics, National Institute for Materials Science, Japan

[b]Department of Applied Physics and Physico-Informatics, Faculty of Science and Technology, Keio University, Japan

[c]Faculty of Engineering, Gunma University, Japan

[d]Department of Mechanical Engineering, Faculty of Science and Technology, Keio University,Japan

Superconducting nanowires are attractive for the low-dimensional transport study, as well as for future quantum nanodevices, such as single-photon detector and quantum phase-slip qubits. Recently, free-standing carbon nanotubes as nanowire templates for material deposition has been developed.[1] In this report, we present results on the one-dimensional (1D) superconductivity in nanowires produced by coating suspended carbon nanotubes with a Niobium-Nitride (NbN). All electrical transport measurements are carried out at low temperatures from 5 K to 20 K. The wire width $W = 10$ nm nanowire shows the superconductor-insulator transition, and $W = 25$ nm nanowire begins to show the superconducting fluctuation. From the resistance-temperature characteristic curves, the signatures of the 1D superconductivity with phase-slip events are observed in $W \geq 25$ nm nanowires.

At the Conference, we will report the details of the fabrication and transport characteristics of ultrathin NbN nanowires on suspended carbon nanotubes.

1. Bezryadin, A., Lau, C. N., and Tinkham, M. (2000). "Quantum suppression of superconductivity in ultrathin nanowires". Nature vol. 404, pp. 971-974.

PS5.26 A New Heat-Capacity Anomaly at the Melting Transition in the Second Layer of ^{3}He on Graphite

S. Nakamura, K. Matsui, T. Matsui, and Hiroshi Fukuyama

Department of Physics, The University of Tokyo, Japan

The second layer of helium on graphite at high densities forms a compressible two-dimensional (2D) solid with a triangular lattice which is incommensurate (IC) to the first layer. For films of three or more layers thick, rounded heat capacity (C) peaks were observed in the previous experiments using a Grafoil substrate at $T \geq 0.5$ K both for ^{3}He [1] and ^{4}He [2]. The peak temperature increases with increasing density until it is finally saturated. Although the peaks are likely associated with melting transitions of the 2D solids, the nature of the transition is not known in detail until now. Here we report a new feature of the melting C anomaly observed for the second layer IC solid of ^{3}He, but not for ^{4}He. In this experiment, a ZYX exfoliated graphite was used instead of Grafoil as it has a surface coherence length ten times larger than Grafoil. The feature involves the sharpness of the peak as well as a strong asymmetry in T, *e.g.*, a λ-shaped or BCS type anomaly, at three densities between 19.7 and 21.4 nm^{-2} where a part of ^{3}He atoms are promoted to the third layer as a liquid phase. On the other hand, similar C peaks observed for ^{4}He films are always broad regardless of substrate and density, and so far not been observed to be asymmetric. The strong contrast between ^{3}He and ^{4}He is probably related to the difference in stiffness of the first layer, in exchanging atoms with adjacent layers, or, more interestingly, in the universality class of the melting transition.

[1] S. W. Van Sciver, Phys. Rev. B **18**, 277 (1978).
[2] D. S. Greywall, Phys. Rev. B **43**, 309 (1993).

PS5.27 Quantitative Ratio between Heat Flows due to Sound and Diffusion in Superfluid Helium

K. E. Nemchenko[a], Yu. V. Rogov[b], and S. Rogova[a]

[a]Energy Physics Department, Karazin Kharkiv National University, Kharkiv, Ukraine

[b]Research associate 'Accelerator', NSC Kharkiv Institute of Physics and Technology, Kharkiv, Ukraine

It is known that in superfluid ^{3}He-^{4}He mixtures temperature and concentration relaxation is defined not only by second sound mode like in pure ^{4}He, but by the dissipative diffusion mode too. So, when considering the problem of the temporal evolution of heat flow in helium mixtures, it is necessary to take in account both modes.

Amplitudes relations of temperature or concentration in competing hydrodynamic modes do not give a complete picture of the problem with the periodic heat sources placed in helium. The fact is that the heat flows are determined by velocity of perturbations propagation in helium rather than by amplitudes relation. The aim of this report is to clarify the question which of the modes gives a greater contribution to propagation of heat.

Starting from the two-fluid hydrodynamic model quantitative contributions of second sound mode and dissipative thermal conductivity mode to total heat flow in superfluid ^{3}He-^{4}He mixtures is studied. The problem is considered in a cell with heat sources of the form $Q_0 \cos^2(\omega t)$ at one side. Analytical expressions for space-time temperature and heat flow dependence were obtained and analyzed.

Invited Oral Presentations: Tuesday August 6th

P6.1 Topological superfluids confined in nanoscale slab geometries

L. Levitin[a], R. Bennett[a], A. Casey[a], B. Cowan[a], J. Saunders[a], J. Parpia[b], and E. V. Surovtsev[c]

[a]Department of Physics, Royal Holloway University of London, Egham, TW20 0EX, UK[b]Department of Physics, Cornell University, Ithaca, NY 14853, USA

[c]Kapitza Institute for Physical Problems, ul. Kosygina 2, Moscow, 119334, Russia

Nanofluidic samples of superfluid ^{3}He provide a route to explore odd-parity topological superfluids and their surface, edge and defect-bound excitations under well controlled conditions. We have cooled superfluid ^{3}He confined in a precisely defined nano-fabricated cavity to well below 1 mK for the first time. We fingerprint the order parameter by nuclear magnetic resonance, exploiting a SQUID NMR spectrometer of exquisite sensitivity. We demonstrate that dimensional confinement, at length scales comparable to the superfluid Cooper-pair diameter, has a profound influence on the superfluid order of ^{3}He. The chiral A-phase is stabilized at low pressures, in a cavity of height 650 nm. At higher pressures we observe ^{3}He-B with a surface induced planar distortion. ^{3}He-B is a time-reversal invariant topological superfluid, supporting gapless Majorana surface states. In the presence of the small symmetry breaking NMR static magnetic field we observe two possible B-phase states of the order parameter manifold, which can coexist as domains. Non-linear NMR on these states enables a measurement of the surface induced planar distortion, which determines the spectral weight of the surface excitations. The expected structure of the domain walls is such that, at the cavity surface, the line separating the two domains is predicted to host gapless states, protected by symmetry and topology. Increasing confinement should stabilize new p-wave superfluid states of matter, such as the quasi-2D gapped A phase. On the other hand, a cavity of height 1000 nm may stabilize a novel striped superfluid, with spatially modulated order parameter.

O6.1 Self-organized criticality in quantum crystallization of ^{4}He in aerogel

R. Nomura, H. Matsuda, A. Ochi, R. Isozaki, and Y. Okuda

Department of physics, Tokyo Institute of Technology, Tokyo 152-8551, Japan

We studied crystallization of superfluid ^{4}He in silica-aerogels to investigate the effect of disorder on dynamics of the first order phase transition at very low temperatures. In the low temperature limit, thermal fluctuation ceases and novel quantum phenomena are expected to emerge in the dynamics of the quantum matter. The way of the crystallization of ^{4}He in aerogels showed a dynamical transition due to the competition between thermal fluctuation and disorder: crystals grew via creep at high temperatures and via avalanche at low temperatures[1]. In the avalanche growth, critical overpressure for the nucleation was found to be temperature independent, indicating that crystallization proceeded by the macroscopic quantum tunneling through the disorder[2]. Avalanche size distribution was measured in the quantum growth regime and followed a power law in a length scale smaller than a large-scale cutoff size. Thus the crystallization in the quantum regime showed the self-organized criticality[3]. While the exponent of the power law was nearly temperature independent, the cutoff decreased with warming toward the transition temperature. Recently, it was observed that a superfluid pocket was formed completely surrounded by crystals in an aerogel when the sample cell was pressurized at constant temperatures in the creep regime and, surprisingly, it crystallized by cooling in the quantum regime. This finding would raise a question about the mass transfer which was possibly related to the supersolidity of ^{4}He in aerogel

1. R. Nomura *et al.*, Phys. Rev. Lett. 101, 175703 (2008).
2. H. Matsuda *et al.*, Phys. Rev. E 87, 030401(R) (2013).
3. R. Nomura *et al.*, J. Phys. Soc. Jpn. 80, 123601 (2011).

O6.2 Phase Diagram of a Classical Quasi-One-Dimensional Electron System

D.G. Rees[a,b], N. Beysengulov[b,c], H. Ikegami[b], D.A. Tayurskii[c], and K. Kono[b]

[a]NCTU-RIKEN Joint Research Laboratory, National Chiao Tung University, Hsinchu, Taiwan

[b]Low Temperature Physics Laboratory, RIKEN, Wako-shi, Japan

[c]Institute of Physics, Kazan Federal University, Kazan, Russia

Surface-state electrons (SSE) on a liquid helium substrate form a model two-dimensional (2D) electron system. Because the Coulomb interaction between electrons is essentially unscreened, the electrons form a triangular lattice, the Wigner crystal, at low temperatures. Here we investigate the Wigner crystallisation of SSE confined in a 10 μm-wide microchannel filled with superfluid ^{4}He. Electrodes at the microchannel edges and under the helium surface are used to control the parabolic confinement potential and the electron density, respectively. The SSE resistivity increases when the electrons form a Wigner crystal, due to the depression of the helium surface beneath each electron. By measuring the SSE current along the microchannel we are therefore able to study Wigner melting in a quasi-one-dimensional (Q1D) geometry. We find that the melting of the Q1D system depends not only on the electron density, as in the 2D case, but also on the confinement energy; for sufficiently strong confinement at a given temperature, the system is crystalline for all densities. Furthermore, the Wigner transition depends on the commensurability of the electron lattice with the confinement potential. This leads to striking oscillations in the current as the electron density changes, when the system is close to melting. The number of electron rows formed in the microchannel can therefore be determined, from more than 30 rows, down to a single electron chain[1].

1. H. Ikegami, H Akimoto, D.G. Rees and K. Kono. "Evidence for Reentrant Melting in a Quasi-One-Dimensional Wigner Crystal". Phys. Rev. Lett. **109**, 236802 (2012).

O6.3 Gas-Liquid Transition and Elementary Excitations in Monolayers of Helium-4

S. Nakamura, K. Matsui, T. Matsui, and Hiroshi Fukuyama

Department of Physics, The University of Tokyo, Japan

The Kosterlitz-Thouless (KT) type superfluid transition in 2D Bosons has been experimentally studied for decades in ^{4}He thin films adsorbed on various substrates. However, little is known about the superfluidity and its relationship to elementary excitations in truly 2D Bose systems, such as monolayers of ^{4}He on graphite. Here, we report the latest results of our heat-capacity (C) measurements for the second layer of ^{4}He on ZYX exfoliated graphite whose microcrystalline size is at least ten times larger than that of Grafoil, a commonly used substrate in previous experiments. At low densities (ρ) below 16 nm^{-2}, where ρ includes the first layer of 12 nm^{-2}, we found C anomalies at $T = 0.73$ K much sharper than those in the previous study using Grafoil, with the logarithmic divergence around the critical point. The observed size dependence and the critical behavior allow us to assign the anomaly to the gas-liquid transition unambiguously, which is in good agreement with the path integral Monte Carlo calculation. At $16.0 \leq \rho \leq 18.7$ nm^{-2}, we found a rounded C bump at $T = 0.9$–1.0 K, whose T- and ρ-dependences are qualitatively different from the sharp anomaly of the gas-liquid transition, but surprisingly, they are similar to those observed with Grafoil at the same densities, which indicates the absence of the size effects. We infer that films in this density region form a uniform and nearly ideal 2D Bose liquid, and that the C bump observed should not be associated with a singularity of phase transitions. The T-dependence of C below 0.8 K of the liquid is nicely described as a summation of *phonon* and *roton* contributions. This is presumably the first experimental evidence for the existence of these two kinds of elementary microscopic excitations in monolayers of ^{4}He. We compare our results with current microscopic calculations.

P6.2 **Higgs bosons in particle physics and in condensed matter**

G.E. Volovik

O.V. Lounasmaa Laboratory, School of Science and Technology, Aalto University, Finland
L.D. Landau Institute for Theoretical Physics, Moscow, Russia

Higgs bosons – the amplitude modes – have been experimentally investigated in condensed matter for many years. An example is superfluid ^{3}He-B, where the broken symmetry leads to 4 Goldstone modes and at least 14 Higgs modes, which are characterized by angular momentum quantum number J and parity (Zeeman splitting of Higgs modes with $J = 2^+$ and $J = 2^-$ in magnetic field has been observed in 80's [1]). Based on the relation $E_{J+}^2 + E_{J-}^2 = 4\Delta^2$ for the energy spectrum of these modes, Yoichiro Nambu [2] proposed the general sum rule, which relates masses of Higgs bosons and masses of fermions. If this rule is applicable to Standard Model, one may expect [3] that the observed Higgs boson with mass $M_{\rm H1} = 125$ GeV has a Nambu partner – the second Higgs boson with mass $M_{\rm H2} = 325$ GeV. Together they satisfy the Nambu relation $M_{\rm H1}^2 + M_{\rm H2}^2 = 4M_{\rm top}^2$, where $M_{\rm top}$ is the top quark mass. Also the properties of the Higgs modes in superfluid ^{3}He-A, where the symmetry breaking is similar to that of the Standard Model, suggest the possible existence of two electrically charged Higgs particles with masses $M_{\rm H+} = M_{\rm H-} \sim 245$ GeV, which together obey the Nambu rule $M_{\rm H+}^2 + M_{\rm H-}^2 = 4M_{\rm top}^2$. A certain excess of events at 325 GeV and at 245 GeV has been reported in 2011, though not confirmed in 2012 experiments.

1. O. Avenel, et al. PRL **45**, 1952 (1980); R. Movshovich, et al. PRL **61**, 1732 (1988).
2. Yoichiro Nambu, Fermion - boson relations in BCS type theories, Physica D **15**, 147 (1985).
3. G.E. Volovik and M.A. Zubkov, Nambu sum rule in the NJL models: from superfluidity to the models of top quark condensation, Pis'ma ZhETF **97**, 344 (2013).

Author Index