Session 25AP

Vortices at the A-B phase boundary in superfluid ^{3}He **25AP1**

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The critical velocity for creating vortices in superfluid ^{3}He is much smaller for the A phase than for the B phase. However, since the vortices in the A phase have two quantum of circulation and the vortices in the B phase only one quantum, it is difficult for a vortex to penetrate through the A-B interface. Motivated by recent experiments, we have calculated the vortex structure in the A phase in the presence of the phase boundary. The calculations show at least two stable configurations where half-quantum vortex cores are formed at the boundary. Depending on the flow there appear either two separate vortices, both with two half-quantum cores, or one larger vortex with two cores at the boundary and the remaining circulation appearing between these cores near the boundary.

On the Helmholtz-Kelvin Instability. **25AP3**

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We study the behavior of the interface between the c- and d-phases of a phase-separated ^{3}He-^{4}He liquid mixture in the presence of superflow in the d-phase. The superflow produces the Helmholtz-Kelvin instability in the system. Here we consider several types of the instability: (i) quantized vortex in the superfluid liquid beside the superfluid-normal interface; (ii) quantized vortex line parallel to the interface in the field of gravity; (iii) the tangential flow of the superfluid component with respect to the normal fluid in the direction parallel to the flat interface. In these cases the Helmholtz-Kelvin instability has a threshold character due to the surface tension and acceleration for the liquid normal to interface. The presence of the threshold results in the quite different scales of the typical distances.

25AP4 Interfacial Tension of ^{3}He-^{4}He Mixture in the Low Temperature Region

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Recently, we reported that the interfacial tension of ^{3}He-^{4}He mixture at saturated vapor pressure shows the T^2-dependence from 0.4K down to 0.15K. In the present work, we measured this tension using a capillary-rise method because of the increase in viscosity with lowing temperature. Change in the capillary-rise was obtained from the capacitance change of two capacitors with different gap widths. From a preliminary experiment, it was found that the temperature dependence of this tension deviates at low temperatures from the T^2-dependence extrapolated from 0.4K.

25AP5 Equations for the Order Parameter and Effective Magnetic Field for Nonunitary Phases of Superfluid Fermi Liquids with Spin-triplet p-wave Pairing

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We have derived the systems of coupled equations for the components of the order parameter and effective magnetic field for nonunitary phases of neutral paramagnetic superfluid Fermi liquids (SFLs) with spin-triplet pairing in strong static uniform magnetic field at any temperatures from the interval $0 < T < T_c$ (T_c is the normal-superfluid transition temperature). In deriving the equations for nonunitary SFLs of $^3He-A_2$ type we have used generalized Fermi-liquid approach and have taken into account Landau spin-exchange amplitudes F_0^a, F_2^a and for dense superfluid neutron matter (existing in the fluid core of neutron stars) we have chosen SkP parameterization of the effective Skyrme interaction between neutrons.

25AP6 Two particle-hole excitation in fermionic quantum liquids

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We formulate a microscopic theory for the dynamic structure function of ^{3}He and other strongly interacting Fermi liquids, which is a generalization of correlated basis function theories for the dynamics of ^{4}He and includes time–dependent *two–particle–two–hole* excitations. Additionaly it is a systematic extension of the random–phase approximation (RPA). Comparison with numerical results show a significant improvement over RPA predictions while maintaining the accuracy of prediction of ground–sate quantities like the static structure function.

Investigation of the Size Effect in "Catastrophic Relaxation" in ^{3}He-B **25AP7**

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"Catastrophic relaxation" refers to a magnetic relaxation process which disrupts the homogeneous spin precession in NMR experiments on superfluid ^{3}He-B in the non-hydrodynamic regime. A model of this (unexplained to date) phenomenon describes it in terms of the development of instabilities which nucleate at the walls of experimental container. Such a model predicts an appreciable dependence of the temperature of the onset of the catastrophe on the size of experimental volume. An appropriate sensor of the onset of the catastrophic relaxation is the long-lived coherent dynamic spin state, the homogeneously precessing domain (HPD). We have constructed a cell to investigate this size effect on the catastrophic relaxation in pulse NMR measurements over a wide range of magnetic fields. The experiment is in the initial stage of testing.

The First Sound Velocity and Attenuation Of Supersaturated Superfluid ^{3}He - ^{4}He Solutions Under Elevated Pressure **25AP8**

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The experimental study of concentration dependencies of the first sound attenuation coefficient in superfluid ^{3}He - ^{4}He mixtures for saturated and supersaturated regions at 0-10 at has been carried out. The original technique of continuous changing of the concentration in situ by varying osmotic and thermomechanic pressures was used that allowed the measurements in the metastable long-lived phase of superfluid mixtures to be performed. It was shown that the data obtained are in good agreement with the theory of sound propagation in a gas of fermi-excitations. Corresponding values of effective mass and relaxation time of ^{3}He quasi-particles were taken from the analysis of the experimental data available. The excess sound attenuation was not registered in the supersaturated region within the accuracy experiment.

Vibrating Wire Measurements in Dilute ^{3}He-^{4}He Solutions in Ballistic Regime **25AP9**

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We present our high sensitivity vibrating wire resonator data on dilute mixtures at ultra low temperatures. Measurements have been performed from 1.7 % up to 9.5 % ^{3}He concentration. A DC SQUID readout of the resonator gave an extremely good signal to noise ratio even at low magnetic fields. The data suggests that our experiment has cooled dilute mixtures to the lower temperature than in the earlier experiments has been reached. The heat leak to the helium sample was extremely small so that the helium would have remained below 1 mK for several months, if the system had not been heated deliberately.

25AP10 A Spin Laser? The Persistent Precessing Domain in Superfluid ^{3}He-B at Ultralow Temperatures

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We present measurements of various properties of the persistent precessing domain (formerly PIS) in superfluid ^{3}He-B. These exotic NMR domains can only be excited at ultralow temperatures and at the lowest temperatures may freely precess for periods of 2000 seconds. We can identify various behaviours depending on the texture and magnetic field gradient. We can create the domain with a short generating pulse. We can excite the domain continuously but only with an excitation frequency *higher* than that of the domain precession and, remarkably, we can excite and sustain the precession by the application of white noise. Thus, unusually, the coherent domain can extract energy from an incoherent energy source.

25AP11 Steady Gradients of the Temperature and Concentration in Superfluid ^{3}He - ^{4}He Solutions

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The temperature and concentration gradients ∇T and ∇x are measured in a superfluid ^{3}He - ^{4}He mixture with a concentration of 9.8% ^{3}He in the temperature range 50-500 mK. The gradients are produced by a steady thermal flow $\dot{Q}$ and registered by two thermometers and two concentration gauges are placed at 1 cm interval. The dependencies of ∇T and ∇x on $\dot{Q}$ and T are investigated at $\dot{Q} = 0,\ 5$ and 21.8 μW. The onset of the convection is observed where the dependencies $\nabla T(\dot{Q})$ and $\nabla x(\dot{Q})$ deviated from the linear region. It is shown that the relationship between the steady values of ∇T and ∇x in the superfluid solutions is in agreement with a theoretical model derived from the dependencies on T and x of the osmotic pressure. The relaxation processes in superfluid ^{3}He - ^{4}He solutions are studied too.

25AP12 Novel Superfluid Transitions of ^{3}He in the Bulk and on the Surface Layer

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The superfluid (SF) phase transitions of ^{3}He cannot be understood properly in terms of the Fermi-liquid theories. For this reason, a novel two-stage Fermi-Bose-liquid model of superfluidity in Fermi systems has been proposed (Int. J. Mod. Phys. B12, 2151 (1998)). This novel superfluidity results from the BCS-like p-wave pairing of fermions and the SF single particle and pair condensations of two-fermion composite bosons. Here, we study the distinctive SF transitions of ^{3}He in the bulk and on surfaces within the proper SF Bose-liquid model. We prove that at low temperature the A and B phases arise on surfaces and in the bulk, respectively. We show that the A-B transition temperature decreases on the surface layer and the surfaces play a role similar to a magnetic field or a rotation, which shifts the A-B transition to lower temperatures. The obtained results agree with experiments.

A macroscopic realization of the weak interaction **25AP13**

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A.J.Leggett suggested in 1977 that a permanent electric dipole moment due to the parity-nonconserving electron-nucleon interaciton could be measured, even though it is extremely small, in the superfluid ^{3}He-B because the moment should be proportional to the size of the sample in this system. In our planned experiments, a high electric field of up to 6 kV/cm is applied between two parallel electrodes in the ^{3}He sample. We expect to observe the NMR frequency of the lowest-lying spin-wave mode trapped by the liquid crystal-like texture of the B phase rotation axis in our geometry. The interaction of the electric field and the macroscopic permanent electric dipole moment will cause a small change in the texture and hence a small increase in the frequency of the spin wave mode . We present the design of our sample cell and discuss the set-up of our experiments.

Effect of Orbital Ferromagnetism on Textures in a Slab of Superfluid ^{3}He-A **25AP14**

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The effect of orbital ferromagnetism on the Fréedericksz transition of a uniform **l** texture of ^{3}He-A in a slab geometry has been calculated. We find the Fréedericksz transition magnetic field is altered in opposite directions for **l** parallel and antiparallel to the applied field by an amount proportional to the ferromagnetic moment. The calculation has been performed for both the dipole-locked and unlocked cases. The consequent changes in the hydrodynamics of a thin disk of ^{3}He-A undergoing torsional oscillations has been determined.

On the magnetism of liquid nitrogen-liquid oxygen mixtures **25AP15**

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The longstanding problem of the liquid oxygen magnetism seems to be solved by taking into account the possibility of $O_2 - O_2 - O_2$ and $N_2 - O_2 - O_2$ clusters formation. The backgrounds for such conclusion are the oxygen EPR measurements as well as quantum-chemical calculations.

25AP16 Stationary convection in a dilute rotating ^{3}He–superfluid ^{4}He mixture: linear stability analysis

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A fluid layer subject to a vertical temperature gradient will start convecting when the temperature difference across the layer exceed a critical value. A linear stability analysis is performed to calculate this critical value for a dilute ^{3}He–superfluid ^{4}He mixture rotating about a vertical axis. Significant differences from the result for a classical fluid are shown which arise from the presence of mutual friction in the equations of motion. Unlike the non-rotating case these differences should be experimentally observable.

25AP17 Light-Scattering Measurements on Superfluid Fog

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Diffusing-wave spectroscopy is used to probe the dynamics of superfluid ^{4}He fog created using an ultrasonic transducer underneath the liquid helium surface. Correlation studies of the light scattered from the fog droplets show that their motion is ballistic for times shorter than a characteristic viscous time τ_v = 10^{-5} s, and then reflects interaction with other droplets at longer times. The average relative velocity between the droplets is small compared to the velocity of the droplets being injected into the fog, but increases proportionally to that injection velocity. These studies help to understand the steady-state dynamics of the fog creation process.
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25AP18 Local Quantum coherence and the superfluid phase

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Superfluidity ,in the strong interaction limit, is associated to non vanishing off diagonal elements of the average density matrix associated to a local state i.e. to the occurence of a macroscopic quantum coherence phenomenon. In the Hard Core Bosons model the local state is a quantum superposition of a Spin up state (site s occupied by a particle) or a Spin down state (empty site). In the Hubbard model the local state is a superposition of the two degenerate components of the ground state of the local part of the Hamiltonian at half filling . This approach allows a systematic expansion around the mean field at fixed order parameter in terms of the coordination number of the lattice and of deviation from half-filling. In the Hubbard case this expansion simplifies in the limit of a large ratio of the interaction strength to the hopping amplitude where Hard core bosons model results are recovered as expected..

Calculation of λ -Transition Temperature in Liquid ^{4}He **25AP19**

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In experiments of Liquid ^{4}He, the elementary excitation energy varies with changing of the temperature. This is caused by the property that the total energy depends non-linearly upon the number-distribution function of elementary excitations. When we take this non-linear dependence into consideration, we can numerically calculate the temperature of λ transition. The calculated results are 2.18 K for the saturated vapor pressure, 2.10 K for 10 bar, and 1.92 K for 20 bar. Other calculated values are 2.8 K after Landau, and 3.16 K after London for the saturated vapor pressure. Comparing the present calculated value with Landau's value and London's value, the present results are well in accord with the experimental data (2.172 K for the saturated vapor pressure).

Neutron scattering study of the liquid helium dispersion curve. **25AP20**

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The long term studies of the excitation spectrum of bulk liquid helium on DIN-1M, DIN-2PR, and DIN-2PI spectrometers (IBR-30 and IBR-2 reactors, Dubna) brought interesting results in parallel with the investigations at other neutron centers. New data treatment of the recent high-resolution high-precision measurements of the dynamic structure factor of liquid helium carried out by inelastic neutron scattering are reported. New interpretation of the temperature dependence of the dynamic structure factor at 0.5-0.6 inverse Angstroms is discussed.

Acoustic Properties of Liquid ^{4}He Measured by Rayleigh-SAW **25AP21**

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Damping and velocity of the Rayleigh surface acoustic waves (SAW) were measured in liquid ^{4}He. Rayleigh-SAW propagates along the substrate surface by emitting the compressional waves into the liquid and thus the damping of the Rayleigh-SAW is determined by the acoustic impedance of the surrounding liquid ^{4}He. Temperature dependence agreed well with the reported values of the impedance and the superfluid transition in ^{4}He was clearly seen. We also set up the reflection plate 2mm above the SAW device and the emission waves were reflected by it. They were converted into the SAW again and used to measure the velocity and the damping of ultrasound in liquid ^{4}He separately. It will be discussed about the applications of this sensor for the superfluid ^{3}He in narrow space and superfluid ^{3}He film.

25AP22 Velocity and Damping of the SH-SAW in Normal Liquid ^{3}He

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We developed the shear horizontal surface acoustic wave (SH-SAW) sensors in order to investigate the viscoelastic properties and the transverse sound in normal and superflid ^{3}He. SAW was generated and detected by two sets of interdigital transducers on $LiTaO_3$ substrate. Distance between generator and detector was 20mm. SAW frequency was 69MHz and operated in the pulse mode. In the SH-SAW the substrate displacement is transverse to the propagation direction in the substrate surface. It couples to the viscosity of the surrounding liquid ^{3}He. Velocity and damping of SH-SAW were measured in normal liquid ^{3}He down to 12mK. Temperature dependences of the velocity and the damping were explained well by assuming the viscoelasitc properties of the normal liquid ^{3}He.

25AP23 Neutron Radiography of Helium II

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We have used a neutron radiography technique to investigate the spatial distribution of ^{3}He atoms in very dilute liquid ^{3}He-^{4}He mixtures at temperatures below the superfluid transition temperature. By imposing heat currents and monitoring the subsequent redistribution of ^{3}He within the sample volume we obtain a direct measurement of the relevant mass diffusion coefficient Data from these experiments provides a striking demonstration of the manner in which the distribution of impurity atoms within the liquid can be influenced by the presence of a free surface.

25AP24 Josephson π states in superfluid ^{3}He B-phase/A-phase/B-phase junctions

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Bistable π states in superfluid ^{3}He weak links have been observed by Marchenkov *et al*. in Berkeley. In order to elucidate the mechanism of π-state formation, we study B-phase/A-phase/B-phase (BAB) Josephson junctions which might be possible to model weak links in superfluid ^{3}He. We derive a general formula for supercurrent through hybrid junctions with anisotropic Cooper-pair condensates, and apply it to BAB junctions. We show that current-phase relations in BAB junctions possess major characteristics of the observed π state with higher critical current (**H** state), and propose a new mechanism of π-state formation due to $\hat{\boldsymbol{l}}$ texture in the A phase ($\hat{\boldsymbol{l}}$-texture mechanism). The effect of $\hat{\boldsymbol{n}}$ texture in the B phase is also discussed.

Equilibrium simulations of weak links in p wave superfluids **25AP25**

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Simulations of effectively two-dimensional helium-3 weak links have been carried out using the Ginzburg-Landau theory. The bulk phases (A or B) can be varied generally, and many physically relevant situations are tested. Parameters are chosen to mimic recent measurements of such single-aperture systems close to T_c, and the calculation clarifies the interpretation of the observed "π states". In junctions narrower than $3\xi_{GL}$ "isotextural" pinhole results are reproduced, with low-critical current π states due to the $\cos(2\Delta\phi)$ harmonics in the Josephson coupling. However, in larger junctions the isotextural picture fails, and one finds more complicated behavior of the order parameter and the mass and spin currents. Here π states with large critical currents and both continuous or hysteretic $J(\Delta\phi)$ are found.

Quantum Interference in superfluid ^{3}He **25AP26**

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We report a double-path quantum interference experiment involving superfluid ^{3}He. Using a geometry analogous to the superconducting d.c. SQUID, two superfluid ^{3}He weak links separate the two arms of a loop of superfluid ^{3}He. Using the rotation of the Earth, we can control a quantum phase shift between the phase drops across each weak link. The variation with rotation flux of the critical current of the device produces the typical cosine-like interference pattern with periodicity determined by the ^{3}He quantum of circulation. If the current-phase relations of the two superfluid weak link arrays are non-sinelike, we find that the interference pattern is modified from its cosine-like behavior. In addition, multiple possible curves are observed at equal temperatures. Each curve is robust for every passage through T_c.

Flow Properties of ^{3}He in 10 nm-sized Structures **25AP27**

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We have shown that 10 nm diameter holes can be fabricated with a density of 10^5/mm^2 in 15 nm thick nitrocellulose films. One of these films was glued to a grid (1 mm^2 open area) and then placed into the center of a 7 μm thick Kapton membrane (9 mm dia.) which was part of the capacitative drive of a Helmholtz resonator. This resonator has been safely operated down to 0.2 mK. During filling with ^{3}He a pressure difference across the membrane of 100 mbar could be applied. With a SQUID-based readout system the membrane's movement was detected with a $\sim$4 nm/ϕ_0 sensitivity. With this device high Josephson currents in superfluid ^{4}He should become measurable at sizeable superfluid densities at T$\sim 10^{-4}$T$_c$. Our experiments on normal fluid ^{3}He have shown a temperature independent time constant (τ $\sim$20 min.) of the resonator. In superfluid ^{3}He-B the response to pressure steps became short ($\sim$30 s).

25AP28 Reconsideration of the paramagnon theory in superfluid ^{3}He

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The paramagnon theory in the superfluid ^{3}He is reconsidered. First, using the perturbation theory up to the third order in the long range interaction related to the hard core potential of ^{3}He, we evaluate the Gor'kov-Éliashberg equation. It is shown that suppression of the density fluctuation in the high density leads to the p-wave triplet pairing at the moderate interaction. Second, we discuss the vertex correction for the paramagnon theory. Although the large mass enhancement in one paramagnon process at the nearly ferromagnetic quantum critical point drastically reduces the transition temperature, the vertex corrections suppress the mass enhancement, and stabilize the p-wave triplet pairing.

25AP29 Vortex-line connections across the AB phase boundary in superfluid ^{3}He

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The order parameter phase is continuous across the boundary between the A and B phases of superfluid ^{3}He, since both belong to the same $L = S = 1$ manifold. Vortex lines therefore do not end at the AB interface, but either lie parallel, coating the interface as a vortex layer, or cross it perpendicularly. In the A phase there exists both a singly and a doubly quantized vortex structure. In most situations the latter forms first because of its much lower critical velocity. Also at the AB interface the dominant interconnection across the boundary is formed by joining one doubly quantized A-phase vortex with two singly quantized B-phase vortices. The simpler topology of a direct connection between one singly quantized vortex in each of the two phases thus does not appear to promote the formation of the singly quantized A-phase vortex. We discuss the experimental evidence and its explanation.

25AP30 Magnetically Stabilized AB Interface in Rotating Superfluid ^{3}He

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Vortex lines in the A and B phases of superfluid ^{3}He have different structure and quantization. How do they then interact at the AB phase boundary? We discuss an experimental setup where the AB interface is stabilized in a long cylindrical container with a magnetic barrier field. It divides the sample in A and B-phase sections which are maintained in a homogeneous low-field NMR environment over the temperature interval where the supercooled A phase exists in the smooth-walled quartz tube. With two independent NMR spectrometers the vortex lines in the two phases can then be studied as a function of the rotation velocity of the cryostat. Simultaneously, by adjusting the barrier field and temperature, the sample can be changed from single phase to two-phase configurations with one or two AB interfaces. Using this setup the first example of a shear-flow instability in superfluids was discovered.

Vortex Lines at an Interface Between Superfluids of Different Symmetry **25AP31**

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What happens to topological defects of macroscopic quantum systems of different symmetry which are in stable contact? We present the first experimental realization of such a situation using the A and B phases of superfluid ^{3}He. We show that the AB interface prevents vortex lines from passing through, owing to a vastly different structure of vorticity in the two phases. The A-phase vortices are deflected at the interface and coat it with a new sheet-like object. At the critical density of vorticity in the sheet the continuous order parameter distribution in the A phase collapses, some lines escape from the sheet and cross over into the B phase as pairs of vortices with hard cores. In the opposite process when the interface is pushed against the B-phase vortices their hard cores disappear and transform to the continuous A-phase textures.

Effect of the Shape of the AB Interface on its Instability in Rotating ^{3}He **25AP32**

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In our experiments the interface between the A and B phases of superfluid ^{3}He is stabilized in a rotating cylindrical sample using a magnetic field gradient. The shape of the interface is determined by competition of magnetic energies of the two phases, surface energy at the interface and at the walls and kinetic energy of the superflow. It can be changed from almost flat and perpendicular to the sample axis to the ring between doughnut of the A phase at the outer sample boundary and the B phase filling the hole in the middle. At a certain rotation velocity the interface becomes unstable and vortices penetrate from the A to the B phase. The critical velocity of the instability is continuous across abrupt transition from the singly-connected to doughnut-shaped configuration of the A phase. This is consistent with our understanding of the process as a corrugation instability of the interface close to the outer sample boundary.

Unresolved Issues in Magnetically Driven Flows of Spin-Polarized Superfluid **25AP33**

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The spin-polarized superfluid ^{3}He A_1 phase is unique in that spin/mass flows can be induced magnetically in its ferromagnetic condensate. Experimental observations of the effect have been made by applying magnetic field gradients across a spin filter and measuring the induced pressure gradient. There are important issues which remain unresolved about the observations. An ideal static magnetic fountain effect has not been seen, and the observed effect has always been accompanied with a characteristic relaxation time. The relaxation time jumps by a factor of 2 near the middle the A_1 phase. The presence of A_1/A_2 phase interface has been speculated to cause the jump. The measured relaxation time increases with the applied field up to 1.4 tesla. The origins of the temperature and field dependence are not well understood. Planned experiments to probe these issues are described in this paper.

25AP34 Unexpected features of weak links in superfluid ^{3}He

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We report measurements of the current-phase relation, $I(\phi)$, of an array of 198 $\sim$100 nm pinholes in superfluid ^{3}He-B with strong controlled magnetic field applied. Unexpected features have been observed:
1. Six different $I(\phi)$'s have been observed for magnetic fields parallel and perpendicular to the flow, instead of at most 4 predicted. Four of the $I(\phi)$'s are stable against rotation of the magnetic field by $\pi/2$.
2. Circulation in the flow loop containing the weak link is reproducible between the cooldowns, but changes with temperature by almost one circulation quantum between 0.5 and 0.95 T_c.
3. On some cooldowns, the circulation is changed by half a circulation quantum from its more usual value. We consider this as possible evidence of formation of "cosmiclike soliton" (Salomaa and Volovik).