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13. ABSTRACT (Maximum 200 words) The research has been directed toward understanding the physics of superfluid phase slippage. The central goal is to observe and quantify acoustic fields radiated from the phase slip microapertures. The sound field contains information about the stochastic processes driving phase slippage. The velocity dependent energy barrier for these processes has been determined. Understanding the acoustic pulses associated with phase slips has led to a demonstration of a superfluid Helium rotation sensor.				
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Final Report
Grant # N00014-94-1-0043
Josephson Acoustic Radiation in Superfluid Helium

Goals:

The research performed under grant #N00014-94-1-0043 was directed towards detecting and measuring acoustic radiation at the Josephson frequency $f_j = \Delta P / \rho \kappa$. Here ΔP is the pressure head driving superfluid ^4He through a submicron aperture, ρ is the density of liquid Helium and κ is the quantum of circulation (h/m_4). The sound is produced from pressure pulses which occur whenever a quantized vortex is nucleated in the aperture. The research program encompasses several interrelated goals:

- Demonstrate the Josephson frequency relation in a superfluid. This has been a "Holy Grail" for over 30 years.
- Determine the stochastic processes that underlie the nucleation of vortices. This affects the bandwidth of the acoustic signal.
- Work toward demonstrating a new kind of sensitive gyroscope; a superfluid device that is an analog of an ac SQUID.
- Provide training to students in low temperature thermo acoustics.

Accomplishments:

- Invention of a method to drive flow through a microaperture at constant pressure head
- The development of an apparatus which has the sensitivity to detect the Josephson sound signal. In recent tests we have detected broadband acoustic radiation but not the narrow band Josephson signal. This was due to using an aperture that did not display simple 2π phase slip dissipation. We are presently changing apertures and continuing the experiment under the AASERT supplement.
- The discovery and determination of a universal energy barrier for vortex formation.
- The demonstration of the superfluid gyroscope. This important and very recent development is the "proof of principle" demonstration that will open the door for development of a very sensitive rotation sensor.
- The discovery of broadband acoustic emission from superflow through apertures. This has led to an understanding of problems associated with phase slip sound in the context of superfluid gyroscopes. It was this understanding that led to the successful gyroscope demonstration

- The development of a thermo-acoustic model that can predict transfer functions for superfluid oscillators and acoustic cavities. The theory has been successfully tested in several resonators
- The development of an improved cryogenic valve.

Publications:

1. Vortex Nucleation in Superfluid ^4He , J. Steinhauer, K. Schwab, Yu. Mukharsky, J.C. Davis and Richard Packard, Phys. Rev. Lett. **74**, 5056, (1995)
2. The Determination of the Energy Barrier for Phase Slips in Superfluid ^4He , J. Steinhauer, K. Schwab, Y. Mukharsky, J.C. Davis and R. E. Packard, J. of Low Temp. Phys., **100**, 281(1995)
3. The Relationship Between the Josephson Frequency and the Arrhenius Rate for Vortex Nucleation in Superfluid ^4He , J. Steinhauer, S. Backhaus and Richard E. Packard. Phys. Rev. B, **52** Oct., 1995
4. Fabrication of a Silicon Based Superfluid Oscillator, K. Schwab, J. Steinhauer and R. E. Packard, IEEE Journal of Micromechanical Systems, **5**, Sept. 1996.
5. The Pressure Dependence of the Intrinsic Critical Velocity in the Quantum Tunneling Regime, Yu. Mukharsky, K. Schwab, J.C. Davis, J. Steinhauer. A. Loshak and R. E. Packard, Manuscript in preparation
6. Study of an Array of superfluid ^3He weak links, Yu. Mukharsky, A. Loshak, K. Schwab, J.C. Davis and R.E. Packard, Proc. of the 21st International Conference on Low Temperature Physics, Czech. Journal of Physics, **46**, 115 (1996)
7. A microfabricated superfluid ^4He "RF Squid", K. Schwab, J. C. Davis and R. E. Packard, Proc. of the 21st International Conference on Low Temperature Physics, Czech. Journal of Physics, **46**, (1996)
8. The intrinsic critical velocity near T_λ , Scott Backhaus, N. Bruckner, A. Loshak, K. Schwab and R. E. Packard, Proc. of the 21st International Conference on Low Temperature Physics, Czech. Journal of Physics, **46**, 127 (1996)
9. A method to maintain superflow at constant pressure drive, S. Backhaus and R. E. Packard, Proc. of the 21st International Conference on Low Temperature Physics, Czech. Journal of Physics, **46**, 2743(1996)
10. An improved low temperature valve, N. Bruckner, S. Backhaus, and R.E. Packard, Proc. of the 21st International Conference on Low Temperature Physics, Czech. Journal of Physics, **46**, 2741 (1996)
11. Properties of Superfluid ^3He Weak links, Yu. Mukharsky, A. Loshak, K. Schwab, J.C. Davis and R.E. Packard, Submitted to Phys. Rev. B

12. Phase slip memory effects in dissipation-free superflow , K. Schwab, J. Steinhauer and R.E. Packard, submitted to Phys. Rev. B
13. Detection of the Earth's rotation using superfluid phase coherence, K. Schwab, N. Backhaus, and R. E. Packard, submitted to Nature

Talks related to the grant projects:

Invited conference presentations:

1. Conference on Quantum Fluids and Solids, Cornell University, Ithaca, NY, June 12-17, 1995 "The Creation of Vortices in Superfluid ^4He ", R. E. Packard
2. Division of Fluid Dynamics, American Physical Society Meeting, Syracuse, NY, Nov. 24, 1996, "Experiments on Single Vortices"

Contributed conference presentations:

1. A new technique for the measurement of intrinsic critical velocities in ^4He , S. Backhaus and R.E. Packard, Conference on Quantum Fluids and Solids, Cornell University, Ithaca, NY, June 12-17,1995
2. Recent Results with a Microfabricated Superfluid Oscillator, Keith Schwab and R. E. Packard, Conference on Quantum Fluids and Solids, Cornell University, Ithaca, NY, June 12-17,1995
3. A Microfabricated Superfluid ^4He "RF Squid", Keith Schwab, Seamus Davis and Richard Packard, XXI International Conference in Low Temperature Physics, Aug. 8-14, 1996 Prague, Czech Republic.
4. A Method to Maintain Superflow at Constant Pressure Drive, Scott Backhaus and Richard Packard, XXI International Conference in Low Temperature Physics, Aug. 8-14, 1996 Prague, Czech Republic.
5. The Intrinsic Critical Velocity Near T_λ , Scott Backhaus, Niels Bruckner, Alex Loshak, Keith Schwab and Richard Packard, XXI International Conference in Low Temperature Physics, Aug. 8-14, 1996 Prague, Czech Republic.
6. An Improved Low Temperature Valve, Neils Bruckner, Scott Backhaus, and Richard Packard, XXI International Conference in Low Temperature Physics, Aug. 8-14, 1996 Prague, Czech Republic.

Invited Colloquia (recent)

1. Physics Department, UC Davis Oct 10, 1995
2. Pennsylvania State University Nov. 10, 1995
3. INFN Laboratory, Legnaro, Padova, Italy Jan. 26, 1996
4. Physics Department Galileo Galilei, University of Padova, Italy March 5 1996
5. Physics Department, University of Manchester, England, March 20, 1996
6. Physics Department, University of Lancaster, England, March 21, 1996
7. Physics Department, University of Birmingham, England, March 22, 1996
8. Physics Department, Ecole Normale Supérieure, Paris, France April 16, 1996
9. CNRS Laboratory, Saclay, France, April 17, 1996
10. Ehrenfest Colloquium. University of Leiden, Holland May 1, 1996
11. Physics Department, University of Trento, Italy, May 15, 1996
12. Physics Department, University of Bayreuth, Germany, May 21, 1996
13. Low Temperature Laboratory, Helsinki University of Technology, June 20, 1996

Completed Ph.D. thesis partially supported under this grant:

J. Steinhauer, "The first determination of both the energy barrier for vortex creation in superfluid ^4He , and the current-pressure relation for a superfluid ^3He weak link", university of California, 1995

K. Schwab, Experiments with superfluid oscillators; design and microfabrication of a superfluid gyroscope, search for rotational modulation of a ^4He rf SQUID analog; vortex nucleation in superfluid ^4He , University of California, 1996

Distribution List:

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