Monday, March 5, 2007 8:00AM - 11:00AM –
Session A32 DAMOP: Focus Session: Rotating Quantum Gases  Colorado Convention Center 402

8:00AM A32.00001 Rotation of fermions in a two dimensional lattice with a harmonic trap
TUN WANG, SUSANNE YELIN, Univ. of Connecticut — Rotation of fermions in a lattice is studied using a Hubbard model. It is found that the fermions are still contained in the trap even when the rotation frequency is larger than the trapping frequency. This is very different from the behavior in continuum. Bragg scattering and coupling between angular and radial motion are believed to make this stability possible. In this regime, density depletion at the center of the trap can be developed for spin polarized fermions.

8:12AM A32.00002 Using custom potentials to access quantum Hall states in rotating Bose gases
ALEXIS G. MORRIS, DAVID L. FEDER, University of Calgary — The exact ground states of zero-temperature rotating Bose gases confined in quasi-two-dimensional harmonic traps are studied numerically, for small numbers of alkali atoms. As the rotation frequency increases, the interacting Bose gas undergoes a series of transitions from one quantum Hall state to another. We have investigated the possibility of facilitating access to specific quantum Hall states through the addition of customized potentials to the existing trapping potential. For the right choice of potential, we show that creation of predetermined quantum Hall states in rotating Bose gases should be possible using current experimental setups. (Research supported by NSERC, iCORE and CFI)

8:24AM A32.00003 Quantized vortex states of strongly interacting bosons in a rotating optical lattice
RAJIV BHAT, B.M. PEDEN, B.T. SEAMAN, M. KRAEMER, JILA, NIST and U. of Colorado-Boulder, L.D. CARR, Colorado School of Mines, Golden, M.J. HOLLAND, JILA, NIST and U. of Colorado-Boulder — The analogy between ultracold atoms in optical lattices and electrons in crystal lattices is a manifestly rich one. If the optical lattice is rotating rapidly, many of the features associated with electrons in strong magnetic fields emerge. Even high correlated effects and quantum states like those underlying the fractional quantum Hall effect can potentially be realized. We examine small square two-dimensional systems with low filling via exact diagonalization of a modified Bose-Hubbard Hamiltonian. In this talk I will present some results showing the effects of the quantization of circulation, the appearance of vortices, and some of the novel features of quantum phase transitions in these systems.

8:36AM A32.00004 Quantum Hall physics in rotating Bose-Einstein condensates
SUSANNE VIEFERS, University of Oslo — A few years ago it was realized theoretically that there is a close analogy between the physics of rapidly rotating atomic Bose condensates (BEC) and the quantum Hall effect (i.e. a two-dimensional electron gas in a strong magnetic field). Due to an extremely rapid development in experimental techniques over the past few years, experiments on BEC are now very close to reaching the quantum Hall regime. In this talk I will review the theoretical connection between these two seemingly very different physical systems, and show how intuition and techniques from quantum Hall physics can be applied to study the properties of rotating Bose condensates.

9:12AM A32.00005 Vortices in two-component weakly interacting Bose-Einstein condensates
SARA BARGI, JONAS CHRISTENSSON, GEORGIOS KAVOULAKIS, KIMMO KARKKAINEN, YONGLE YU, Lund Institute of Technology, Lund University, MATTI MANNINEN, Nanoscience Centre, University of Jyväskylä, Finland, STEPHANIE REIMANN, Lund Institute of Technology, Lund University — Weakly interacting Bose-Einstein condensates that are set rotating, are studied by numerical diagonalization of the many-body Hamiltonian. In particular, we investigate the structure of the lowest-energy states as a function of angular momentum, when pseudospin is introduced. Coreless vortices and vortex lattices in the exact solutions are compared to the results earlier obtained within the Goss-Pitaevskii mean field approach (see for example, Kasamatsu, Tsubota and Ueda, Phys Rev Lett 93, 250406 (2004) and Phys Rev A 91, 150406 (2005)).

9:24AM A32.00006 Persistent flow in a Bose-Einstein condensate
PIERRE CLADE, CHANGHYUN RYU, MICHAEL ANDERSEN, VASANT NATARAJAN, ANAND RAMANATHAN, KRISTIAN HELMERSION, WILLIAM PHILLIPS, National Institute of Standards and Technology — We will describe experiments on the study of quantized flow of Bose-condensed atoms in a multiply-connected trap. This torus-shaped trap is formed by the combination of an elliptically shaped, magnetic trap with a blue detuned laser beam in the middle to exclude atoms from the center of the magnetic trap. The rotation was initiated by transferring the orbital angular momentum from Laguerre-Gaussian photons to the atoms. We have observed that the rotational flow of atoms persists for several seconds, even when the condensate fraction is less than 10%. We have also observed flow with high angular momentum and its splitting into singly charged vortices when the trap in no longer multiply-connected.

9:36AM A32.00007 Vortex-Lattice Phases in the Strongly-Interacting Limit of the Bose-Hubbard Model
DANIEL GOLDBAUM, ERICH MUELLER, Cornell University — We observe a structural phase transition in the vortex lattice described by the rotating Bose-Hubbard model as the system approaches the insulating phase. A weak optical lattice potential pins vortices to the potential maxima (S. Tung, et. al. arXiv:cond-mat/0607697). However, using Gutzwiller mean-field theory in the strongly-interacting limit of the rotating Bose-Hubbard model, we find an interaction driven phase transition from the potential maximum centered vortex lattice to a potential minimum centered configuration. In addition, even closer to the insulating phase, our results suggest a recurrence of the maximum-centered phase.

9:48AM A32.00008 Lifshitz-like transition and enhancement of correlations in a rotating bosonic ring lattice
ANA MARIA REY, ITAMP, KEITH BURNETT, Clarendon Laboratory, University of Oxford, INDBALA SATIJA, George Mason University, CHARLES CLARK, NIST — We study the effects of rotation on one-dimensional ultra-cold bosons confined to a ring lattice. For commensurate systems, at a critical value of the rotation frequency, an infinitesimal interatomic interaction energy opens a gap in the excitation spectrum, fragments the ground state into a macroscopic superposition of two states with different circulation and generates a sudden change in the topology of the momentum distribution. These features are reminiscent of the topological changes in the Fermi surface that occurs in the Lifshitz transition in fermionic systems. The entangled nature of the ground state induces a strong enhancement of quantum correlations and decreases the threshold for the Mott insulator transition. In contrast to the commensurate case, the incommensurate lattice is rather insensitive to rotation. Our studies demonstrate the utility of noise correlations as a tool for identifying new physics in strongly correlated systems.

1Supported by NSF and Research Cooperation

3This work partially supported by NSF grant PHY0456261
10:00AM A32.00009 Vortices of Lattice Bosons Acquire Spin and Fermi Statistics, ASSA AUEBACH, NETANEL LINDNER, Physics Department, Technion, Israel, DANIEL AROVAS, University of California at San Diego — Lattice bosons respond differently to a magnetic field, or a rotation, than continuum bosons, e.g., their Hall conductivity is not a linear function of their density. Such effects are mostly pronounced for hard-core bosons at half filling. For a periodic lattice on a torus threaded by fluxes, we can explicitly construct a conserved SU(2) 'vortex spin' algebra. For odd total vorticity, even-fold spectral degeneracies are discovered on every lattice site. In particular, the single vortex has spin half. The vortex effective mass and spin-orbit coupling are extracted by diagonalizing the Hamiltonian on an nxn lattice. For two vortices, numerical 'vortex-spin' correlations and orbital symmetries are consistent with Fermi and not Bose statistics. We discuss implications of the our results on the 'vortex metal' phase at large magnetic fields.

10:12AM A32.00010 Spin Hall effects for cold atoms in a light induced gauge potential, SHILIANG ZHU, South China Normal University, HAO FU, University of Michigan, CONGJUN WU, University of California, Santa Barbara, SHOU-CHENG ZHANG, Stanford University, LUMING DUAN, University of Michigan — We propose an experimental scheme to observe spin Hall effects with cold atoms in a light induced gauge potential. Under an appropriate configuration, the cold atoms moving in a spatially varying laser field experience an effective spin-dependent gauge potential. Through numerical simulation, we demonstrate that such a gauge field leads to observable spin Hall currents under realistic conditions. We also discuss the quantum spin Hall state in an optical lattice.

10:24AM A32.00011 Rapidly rotating strongly-correlated few bosons, LESLIE O. BAKSMATY, CONSTANTINE YANNIOULEAS, UZI LANDMAN, School of Physics, Georgia Institute of Technology — A small number, N ≤ 11, of bosons in a rapidly rotating harmonic trap, interacting via a contact potential or a Coulomb repulsion, is studied via an exact diagonalization in the lowest Landau level. For both low and high fractional fillings, the bosons localize and form rotating boson molecules (RBMs) consisting of concentric polygonal rings. As a function of the rotational frequency and regardless of the type of repulsive interaction, the ground-state angular momenta grow in specific steps that coincide with the number of localized bosons on each concentric ring. Comparison of the conditional probability distributions (CPDs) for both interactions suggests that the degree of crystalline correlations appears to depend more on the fractional filling than on the range of the interaction. The RBMs behave as nonrigid rotors, i.e., the concentric rings rotate independently of each other. At filling fractions ν < 1/2, we observe well developed crystallinity in the CPDs (two-point correlation functions). For larger filling fractions ν > 1/2, observation of similar molecular patterns requires consideration of even higher-order correlation functions.

10:36AM A32.00012 Symmetry breaking and symmetry restoration for bosonic gases in rotating traps: Rotating boson molecules and Gross-Pitaevskii vortex structures, IGOR ROMANOFSKY, CONSTANTINE YANNIOULEAS, UZI LANDMAN, School of Physics, Georgia Institute of Technology — We recently introduced a new variational wave function for strongly repelling bosons in two-dimensional rotating traps. The approach consists of constructing a single permanent out of displaced Gaussian orbitals that break the rotational symmetry and of subsequent symmetry restoration via projection techniques, thus taking into account correlations beyond the mean field. In our approach, the bosons are localized and form rotating boson molecules (RBMs). The projected wave functions of the RBMs do not violate the circular symmetry; nevertheless, they exhibit crystalline patterns in their intrinsic frame of reference. Gross-Pitaevskii (GP) vortex solutions are also known to break the circular symmetry. Here, we apply projection techniques to restore the broken-symmetry GP solutions. We find that the spectral decomposition of the GP vortex solutions are drastically different from that of the RBMs. The RBM spectra, however, are in agreement with exact diagonalization results in the lowest Landau level.

10:48AM A32.00013 Statistics of vortex trapping in cycledly coupled Bose-Josephson junctions, PARAG GHOSH, University of Illinois, Urbana Champaign, FERNANDO SOLS, Departamento de Física de Materiales, Universidad Complutense de Madrid, TONY LEGGETT, University of Illinois, Urbana Champaign — We investigate the problem of vortex trapping in cyclically coupled Bose-Josephson junctions. Starting with N independent BECs we allow the system to reach a stable circulation by adding a dissipative term in our semi-classical equations of motions. We then ask, inter alia the question: "Starting with an initial normal distribution of total phases with variance ~ N/N and allowing for phase slips, what is the probability to trap a stable vortex with winding number 2πm?" We find that the final distribution of winding numbers is narrower than the initial distribution of total phases, indicating an increased probability for no-vortex configurations. The role of dissipation has been studied in determining the final probability distribution. It is also possible to get a non-zero circulation starting with zero total phase around the loop. The final width of the distribution scales as ~ d × N^α, where α = 0.47 and d < 1 (indicating a shrinking of the final distribution), the actual value of d depending on the strength of dissipation.

8:00AM A33.00001 Quantum-Limited and Ultra-Precision Measurements, JM GEREMIA, University of New Mexico — I will provide a brief overview of the current state of the field of experimental quantum-limited measurements. In particular I will focus on the role of entanglement in metrology and quantum parameter estimation for achieving fundamental uncertainty limits established by quantum mechanics. In addition to summarizing the state of the art as this pertains to experimental implementations, I will conclude by discussing a current proposal to improve existing quantum metrological techniques by exploiting multi-body quantum interactions.

8:36AM A33.00002 Assessing the Quality of Quantum Sensors, PAUL A. LOPATA, U.S. Army Research Laboratory, THOMAS B. BAHDER, U.S. Army Aviation and Missile Research, Development and Engineering Center — A general sensor can be modeled in the following way: a well-characterized physical system is prepared in some initial state, the system then interacts with a classical field through a well-understood mechanism, and then a measurement is made on the original system. From this procedure it is possible to infer the characteristics of the classical field. A number of proposals have been made to develop quantum sensors, whose physical systems (which are prepared, interact with the classical field, and are then measured) are quantum mechanical in nature. In this talk I introduce this general description of quantum sensors and demonstrate how the unitary (interacting) dynamics and probabilistic measurements afforded by quantum mechanics can be used to infer the value of a classical field using a Bayesian statistical analysis. I also discuss the use of the mathematical measure of mutual information to compare different sensors.
can be implemented on a single plane of ions [22x60]. The ion qubit. With a 30 mW Gunn diode oscillator we have observed Rabi flopping rates as high as 

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sensitive terms, the quantum limit scales as [22x179]. This is what we examine in detail. We find that the sensitivity of Sagnac interferometer could be considerably improved by using entangled photons produced by [22x255]. Thus a natural question would be—what is the nature of interference if we replace the single photon source by entangled photon pair source. This optics only with lasers until recently when single photons were used. However, it turns out that the results of interference are no different than with classical [22x271]. State University—When two electromagnetic waves counter-propagate along a circular path in rotation they experience different travel times to complete the [22x279]. It was studied and used in [22x279]. This induces a phase shift between the two counter-propagating waves proportional to the angular velocity of the rotation. It was studied and used in [22x279]. This is the number of systems. These quantum limits remain valid when the Hamiltonian is augmented [22x413]. We find that for this system both \( T_S \) and \( T_N \) remain quite close to the refrigerator temperature. 9:36AM A33.00007 Intrinsic Noise Properties of Atomic Point Contact Displacement Detectors, N. E. FLOWERS-JACOBS, K. W. LEHNERT, JILA, NIST and the University of Colorado, and the Department of Physics, University of Colorado, Boulder, Colorado 80309-0440, USA — By coupling an atomic point contact (APC) to a nanomechanical beam, we measure the noise properties of an APC, an object which is the basis of scanning tunneling microscopy and is used to create electrical contact to single molecules. Using a microwave technique, we detect the resonant motion of the nanomechanical beam at frequencies up to 200 MHz. This measurement is sensitive enough to observe the random thermal motion of the nanomechanical beam at 250 mK. We use this thermal motion to evaluate the noise properties of the APC, demonstrating a displacement imperfection limited by the shot-noise in the number of electrons that tunnel across the APC and observing the force due to measurement backaction. Together, the imperfection and backaction yield a total uncertainty in the beam’s displacement that is 42 times the standard quantum limit. In addition, we detect the beam’s response to piezoelectric, electric, and magnetic forces, and use feedback to “squash” the shot-noise. 9:48AM A33.00008 Heisenberg limited Sagnac interferometry, AZIZ KOLKIRAN, G.S. AGARWAL, Oklahoma State University—When two electromagnetic waves counter-propagate along a circular path in rotation they experience different travel times to complete the path. This induces a phase shift between the two counter-propagating waves proportional to the angular velocity of the rotation. It was studied and used in optics only with lasers until recently when single photons were used. However, it turns out that the results of interference are no different than with classical sources. Thus a natural question would be—what is the nature of interference if we replace the single photon source by entangled photon pair source. This is what we examine in detail. We find that the sensitivity of Sagnac interferometer could be considerably improved by using entangled photons produced by a down-converter. We present analytic results for the sensitivity of the interferometer. In particular, two-photon and four-photon entanglements increase the sensitivity by a factor of 2 and 4 respectively. 10:00AM A33.00009 Generalized Limits for Single-Parameter Quantum Estimation, SERGIO BOIXO, STEVEN FLAMMIA, J.M. GEREMIA, CARLTON CAVES, University of New Mexico — We develop generalized bounds for quantum single-parameter estimation problems for the coupling to the parameter is described by intrinsic multi-system interactions. For a Hamiltonian with \( k \)-system parameter-sensitive terms, the quantum limit scales as \( 1/N^k \) where \( N \) is the number of systems. These quantum limits remain valid when the Hamiltonian is augmented by any parameter-independent interaction among the systems and when adaptive measurements via parameter-independent coupling to ancillas are allowed. 1This work was supported in part by ONR Grant No. N00014-03-1-0426 and AFOSR Grant No. FA9550-06-01-0178. 10:12AM A33.00010 Quantum projection noise limited spectroscopy with ions in a Penning-Malmberg trap. —Progress toward spin squeezed states, NOBUYASU SHIGA, WAYNE ITANO, JOHN BOLLINGER, NIST, Boulder, CO 80305—We describe plans and simulate initial progress towards making spin squeezed states with up to \( \sim 100 \) \(^{87}\)Rb ions in a Penning-Malmberg trap. We use the ground-state electron spin-flip transition, which in the 4.5 T magnetic field of the trap has a transition frequency of 124 GHz, at the ion qubit. With a 30 mW Gunn diode oscillator we have observed Rabi flopping rates as high as \( \sim 7 \) kHz. We will summarize experimental progress on realizing projection noise limited spectroscopy on this transition, which is a prerequisite for demonstrating spin squeezing. For entangling the ions we plan to use a generalization of the few ion qubit phase gate developed at NIST [3] to generate an \( \exp (i\chi J_z T) \) interaction between all of the ion qubits. This interaction can be implemented on a single plane of ions [3] with a motional sideband, stimulated Raman transition. 1Supported by a DOD MURI program administrated by ONR 2D. Leibfried, et al., Nature 438, 639 (2005) 3T.B. Mitchell, et al., Science 282, 1290 (1998).
unequal will discuss recent work [1] aimed at understanding the case of by a magnetic field tuned Feshbach resonance (FR). At equal populations, the superfluidity of resonantly interacting Fermi gases undergoes the well-studied

1 SHEEHY, Ames Lab and Iowa State University — A number of recent experiments have achieved paired superfluidity of trapped fermionic atomic gases. Such


due to surface tension at the superfluid/normal boundary. At higher but still degenerate temperatures, an unpolarized central core remains up to a critical

polarization, but does not deform. In this case, the boundaries are not sharp, indicating a partially-polarized shell between the core and the unpaired atoms, consistent with a second-order phase boundary. The observed temperature dependence supports a phase diagram with a tricritical point. The phase-separated phase is only possible for temperatures below the tricritical point, while the higher temperature phase is a polarized superfluid.

11:51AM B4.00002 Superfluidity in a Strongly Interacting Polarized Fermi Gas, YONG-IL SHIN, MIT — Cooper pairing is the underlying mechanism for the Bardeen-Cooper-Schrieffer superfluid state of equal mixture of two fermionic components. An interesting situation arises when the symmetry between the two components is broken, such as mass, density, or chemical potential. Is the pairing mechanism robust enough to overcome an asymmetric stress and keep driving superfluidity? Does a new form of superfluidity emerge out of two mismatched Fermi seas? We experimentally study these questions in an unequal mixture of strongly interacting ultracold fermionic atoms trapped in a three dimensional harmonic potential. We observe that due to strong interaction, the system maintains superfluidity up to a critical population imbalance, showing Pauli limit of superfluidity [1]. By correlating condensation fraction and in-situ density distribution, we identify that a superfluid has equal densities of two components and spatially separates from a normal gas of unequal densities [8]. Recent experimental results will be discussed. [1] M.W. Zwerlein et al., Science 311, 492 (2006). [2] Y. Shin et al., Phys. Rev. Lett 97, 190407 (2006).

12:27PM B4.00003 The Low-Temperature Phases of Polarized Fermionic Superfluids, DANIEL E. SHEEHEY, Ames Lab and Iowa State University — A number of recent experiments have achieved paired superfluidity of trapped fermionic atomic gases. Such pairing, occurring between two atomic hyperfine-stable species (forming a pseudo-spin 1/2 system), is possible due to the strong attractive interactions provided by a magnetic field tuned Feshbach resonance (FR). At equal populations, the superfluidity of resonantly interacting Fermi gases undergoes the well-studied crossover between Bardeen-Cooper-Schrieffer (BCS) pairing and Bose-Einstein condensation (BEC) as a function of FR detuning (or interaction strength). I will discuss recent work [1] aimed at understanding the case of unequal populations (i.e., imposed spin polarization), an easily controllable experimental knob that is predicted to interrupt the continuous equal-population BCS-BEC crossover, yielding a variety of distinct phenomena including regions of singlet paired superfluid, unpaired polarized normal Fermi liquid, polarized Fulde-Ferrell-Larkin-Ovchinnikov superfluid, polarized magnetic superfluid, and phase-separated mixtures of these uniform states. I will describe the low-temperature phase diagram of such polarized fermionic superfluids, focusing particularly on experimental signatures of the various phases in the inhomogeneous environment of the trap. [1] D.E. Sheehy and L. Radzihovsky, Phys. Rev. Lett. 96, 060401 (2006); cond-mat/0607803 (Annals of Physics, in press).

1:03PM B4.00004 Surface tension and collective modes in population imbalanced Fermi gases in the BCS-BEC crossover regime, THEJA DE SILVA, Cornell University — Motivated by the striking experiments from MIT and Rice University, we study population imbalanced Fermi gases in the BCS-BEC crossover regime. We have calculated the surface tension in the boundary separating superfluid and polarized normal regions in a trap. We show how this surface tension can explain apparent inconsistencies between the two groups. Using several candidate equations of state, we calculate frequencies of the breathing mode, finding that collective mode measurements can distinguish between the various possibilities.

1:39PM B4.00005 The important role of temperature in BCS–Bose-Einstein condensation crossover phenomena with population imbalance, QUIN CHEN, University of Chicago — Any comparison between theory and experiment in the cold Fermi gases requires that one include the effects of non-zero temperature $T$. In this talk we show how to include finite $T$ in a way which is compatible with the generalized BCS-like ground state, assumed in essentially all $T = 0$ calculations of gases with population imbalance. We use a pairing fluctuation theory of BCS–Bose-Einstein condensation (BEC) based on a $T$-matrix formalism. Distinguishing this theory from strict mean-field theories is our self-consistent treatment of incoherent, finite-momentum pairs along with single fermions. This leads to a pseudogap in the fermion excitation spectrum at finite $T$ which is necessary in order to arrive at physically meaningful transition temperatures $T_c(p)$, where $p$ is the polarization. We present phase diagrams in the $p$-$T$ plane with variable scattering length, $1/k_F a$, and identify the regions where bulk superfluidity, normal phases and phase separation appears. For the trapped Fermi gases, we present particle density profiles for general $1/k_F a$ as well as a detailed comparison with recent measurements at both MIT and Rice University. We find reasonably good agreement with these experimental data.


1Supported by NSF Grant No. PHY-0555325 and NSF-MRSEC Grant No. DMR-0213745.

Monday, March 5, 2007 11:15AM - 2:15PM —
Session B4 DAMOP: Population Imbalanced Superfluid Fermi Gases  Colorado Convention Center Korbel 2B-3B

Monday, March 5, 2007 11:15AM - 1:39PM —
Session B32 DAMOP: Strong Field and Ultrafast Physics  Colorado Convention Center 402
11:15AM B32.00001 Spatial Dependence of High Harmonic Generation in Hydrogen Atom. SETH ROSS, G.P. ZHANG, Department of Physics, Indiana State University, Terre Haute, IN 47809 — We used the hydrogen atom as a model and computed the continuum mafvefunction and the transition matrix elements. The total quantum number used is 200 and the number of plane waves is 100. We have done dynamical simulations to mimic the laser and electron interaction. Our calculations can be used to compute the power spectrum in the high harmonic generation region. This gives us the opportunity to see the spatial dependence of high harmonic generations in the hydrogen atom. References: H. Niikura et al., Nature 417, 917 (2002); 421, 826 (2003); G. P. Zhang, Phys. Rev. Lett. 95, 047401 (2005); G. P. Zhang and T. F. George, Phys. Rev. A 74, 023811 (2006)

11:17AM B32.00002 Demonstration of a high brightness injection-seeded soft x-ray laser amplifier using a dense plasma. EDUARDO GRANADOS, YONG WANG, MIGUEL A. LAROTONDA, MARK BERRILL, BRAD M. LUTHER, DINESH PATEL, CARMEN S. MENONI, JORGE J. ROCCA, Colorado State University — There is a great interest in the generation of high brightness beams of soft x-ray laser light. We have conducted a table-top experiment in which we have demonstrated the generation of an intense soft x-ray laser beam by saturated amplification of high harmonic seed pulses in a dense transient collisional soft x-ray laser plasma amplifier created by heating a solid titanium target. Amplification of the seed pulses in the 32.6 nm line of Ne-like Ti generates laser pulses of sub-picosecond duration that are measured to match up to full spatial coherence. The peak spectral brightness is estimated to be \( \sim 2 \times 10^{12} \) photons/(s mm\(^2\) mrad\(^2\) 0.01% bandwidth). The scheme is scalable to produce extremely bright lasers at very short wavelength with full temporal and spatial coherence for applications.

1Work supported by the NSF ERC for Extreme Ultraviolet Science and Technology under NSF Award EEC-0310717.

11:39AM B32.00003 ABSTRACT WITHDRAWN —

11:51AM B32.00004 Quasi Phase Matching and Quantum Path Control of High Harmonic Generation using Counterpropagating Light. XIAOSHI ZHANG, AMY LYTLE, OREN COHEN, HENRY KAPTEYN, MARGARET MURNANE, JILA, UNIVERSITY OF COLORADO, BOULDER TEAM — We demonstrate the first use of a 3 pulse train of counterpropagating pulses to enhance the coherent upconversion of an intense ultrashort laser pulse into the extreme ultraviolet region of the spectrum. This all-optical quasi-phase matching technique uses interfering beams to excite the quantum phase of the generated high-order harmonics, to suppress emission from out-of-phase regions. A wavelength selective enhancement in the flux of up to \( \approx 300 \) is observed at photon energies around 70 eV in Argon, that cannot otherwise be phase matched. We also show that further very large enhancements are possible, presenting a real prospect for orders-of-magnitude improvement in coherent upconversion of lasers into the soft x-ray region of the spectrum. Finally we show that by adjusting the intensity of the counterpropagating light, we can selectively enhance different electron quantum path trajectories, demonstrating attosecond time-scale coherent control of the radiating electron wavefunction.

1We gratefully acknowledge support for this work from the National Science Foundation.

12:03PM B32.00005 Angular momentum control of rotational wave packets. OMID MASIHZADEH, RANDY BARTELS, Colorado State University — A linearly polarized laser pulse forms a rotational wave packet that periodically dephases and rephases at rotational revivals. In a dilute gas, these revivals may be observed for time periods in excess of \( 100 \) picoseconds after the pump that initially formed the rotational wave packet. The dynamics of the rotational wave packet are determined by quantum beating of angular momentum states. We show through numerical integration of Schrödinger’s equation that two non-coincident linearly polarized pump pulses can control the angular momentum distribution of the rotational wave packet. The control over dynamics of these novel wave packets will be discussed.

12:15PM B32.00006 Controlling rotational revivals in asymmetric tops. VINOD KUMARAPAN, LOTTE HOLMEGAARD, SIMON VIFTRUP, CHRISTER BISGAARD, HENRIK STAPFELFELDT, University of Aarhus, EDWARD HAMILTON, TAMAR SEIDEMAN, Northwestern University — We use improved experimental and theoretical tools to demonstrate a novel method for controlling the revival structure of strong-field alignment of asymmetric tops. Experimentally, iodobenzene molecules (which is a near-prolate top) are cooled to \( 1 \) K using an Even-Lavie supersonic valve and non-adiabatically aligned using 800 nm pulses of durations ranging from 200 fs to 2 ps. The alignment is probed by velocity map imaging of \( \text{I}^+ \) fragments produced by Coulomb explosion of the molecules using a 25 fs pulse focused tightly to restrict the volume probed. We show that as the fluence of aligning pulse is increased, the revival structure is simplified to a nearly periodic pattern reminiscent of symmetric tops. Theoretically, non-perturbative solution of the Schrodinger equation demonstrates the generality of the effect, and emphasizes the importance of this new control scheme for the alignment and revival dynamics of asymmetric tops. Classically, the simplified motion at high fluence corresponds to stable rotations about the slowest principal axis (the C-axis) of the molecule.

1Support from the US Department of Energy (Grant No. DE-FG02-04ER15612), the Carlsberg Foundation, the Lundbeck Foundation and the Danish Natural Science Research Council is gratefully acknowledged.

12:27PM B32.00007 Heterodyne control of attosecond pulse generation. THOMAS PFEIFER, University of California, Berkeley & LBNL, LUKAS GALLMANN, ETH Zurich, MARK J. ABEL, PHILLIP M. NAGEL, AURELIE JULLIEN, DANIEL M. NEUMARK, STEPHEN R. LEONE, University of California, Berkeley & LBNL — Adding a weak laser field at a different color to the fundamental in high-order harmonic generation results in a new type of heterodyne mixing in the kinetic energy term of the active electron. Analytical calculations and quantum simulations show that the effect of the weak field is amplified by the strong fundamental laser field that acts as the local oscillator [1]. The photon energy of different attosecond pulses within the produced pulse trains can thus be significantly modified. Two important applications for this phenomenon are the generation of isolated attosecond pulses with multi-cycle driving fields and the shaping of attosecond pulse trains. Ref: [1] T. Pfeifer et al., Phys. Rev. Lett. 97, 163901 (2006)
12:39PM B32.00008 Measurement of higher-order moments of a rotational wave packet dynamics and alignment , KLAUS HARTINGER, RANDY BARTELS, Colorado State University — Field free molecular alignment, attributed to the revivals of a rotational wave packet, has been an area of very active research recently, with numerable potential applications\(^1\). While there is very rich structure and temporal dynamics in the quantum rotational wave packet, so far, measurements have been restricted to just the first moment of the wave packet, i.e., a measurement of \(\langle \cos^2 \theta \rangle\). This measure probes the transient alignment of the molecules, but does not reveal the complete dynamics of the quantum wave packet. A measurement of the rotational wave packet dynamics with a linear optical technique depends only on \(\langle \cos^4 \theta \rangle\) and does not provide information on higher order moments of the alignment. Third-order nonlinear interactions provide information on the \(\langle \cos^4 \theta \rangle\) moment and provide additional information about rotational wave packet dynamics. We present third harmonic generation experiments measuring the transient THG susceptibility, which includes the \(\langle \cos^4 \theta \rangle\) dynamics.


12:51PM B32.00009 In-situ probe of ionization and coherent buildup for high-order harmonic generation in hollow waveguides using counterpropagating light , AMY LYTLE, XIAOSHI ZHANG, MARGARET MURNANE, HENRY KAPTEYN, OREN COHEN, JILA/ University of Colorado — We use counterpropagating light to directly observe, in-situ, the coherent buildup of high harmonic generation in a hollow waveguide. We measure, for the first time, the phase mismatch, \(i.e.\) (coherence lengths) for high photon energies that cannot be case matched with more conventional approaches. We also probe the transition through phase matching, the ionization level at which different harmonic orders are generated, and the change in the coherence length as the intensity of the guided mode evolves along the fiber. These results demonstrate that the hollow waveguide geometry possesses exceptional coherence and a “quasi-one-dimensional” plane wave geometry, in analogy to conventional fiber optics in the visible. This in-situ information also directly prescribes the optimal structures or pulsetrains required for implementing quasi phase matching.

1:03PM B32.00010 High harmonic generation from ions in a capillary discharge , TENIO POP-MINTCHEV, DAVID M. GAUDIOSI, OREN COHEN, MARGARET M. MURNANE, HENRY C. KAPTEYN, JILA, University of Colorado at Boulder and NIST, MICHAEL GRISHAM, BRENDAN REAGAN, MARK BERRILL, JORGE J. ROCCA, Department of Electrical and Computer Engineering, Colorado State University, BANJO’S WALKER, Department of Physics and Astronomy, University of Delaware, NSF-ERC FOR EXTREME ULTRAVIOLET SCIENCE AND TECHNOLOGY TEAM — We demonstrated a significant extension of the high harmonic spectra from noble gases by generating harmonics from ions in a capillary discharge plasma. The discharge plasma eliminates ionization-induced defocusing and ionization loss, allowing photon energies of 160 eV, 170 eV and 275 eV to be generated from xenon, krypton and argon ions, respectively. In addition to extending the spectra, harmonic generation in a capillary discharge results in an enhancement of the flux of up to two orders of magnitude near the harmonic cutoff observed in a hollow waveguide. The use of a capillary discharge plasma as a new medium for high harmonic generation shows great promise for extending efficient harmonic generation to shorter wavelengths.

1:15PM B32.00011 Computational Study of Orientation-dependent Molecular High Harmonic Spectra , ANTHONY DUTOI, TAMAR SEIDEMAN, Northwestern University — Recently, there has been much interest in high harmonic generation (HHG) by aligned molecules [Phys. Rev. A 67 023819, Nature 432 867, Nature 435 470]. During HHG, an electron is ionized and driven back to the cation by a strong, low-frequency field, and radiation is emitted at harmonics of this driving pulse. Because this process is sensitive to the orientation of a molecule, rotational dynamics can be probed on very short time scales. We are working to predict the time-dependent HHG spectra for aligned rotational wavepackets. In conjunction with experiment, these simulations should be valuable for studying the loss of rotational coherence in media such as dense gases. Within the presented formalism, Born-Oppenheimer rotational dynamics are handled exactly, while HHG at any given orientation is estimated by numerical time integration of the one-electron Schrödinger equation. Propagation outside of the integration grid can be handled using an analytical Volkov propagator at the expense of ignoring the cation field at this distance.

1:27PM B32.00012 Effect of nuclear motion on the absorption spectrum of dipicolinic acid\(^1\), ROLAND ALLEN, YURI ROSTOVTSDEV, PETRA SAUER, Texas A&M University — A current scientific challenge is the rapid detection of chemical and biological substances, including bacterial spores. A significant component of spores is the molecule dipicolinic acid (DPA or 2,6-pyridinedicarboxylic acid) and its salts. A variety of spectroscopic detection schemes are being explored, including fluorescence spectroscopy, ultraviolet and visible resonant Raman spectroscopy, and FAST CARS. Using semiclassical electron-radiation-ion dynamics (SERID), we have examined the effect of nuclear motion, resulting from both finite temperature and the response to a radiation field, on the line broadening of the excitation profile of DPA. With nuclei fixed, we find a relatively small broadening associated with the finite time duration of an applied laser pulse. When the nuclei are allowed to move, the excitation spectrum exhibits a much larger broadening, and is also reduced in height and shifted toward lower frequencies. In both cases, the excitation is due to well-defined \(\pi \rightarrow \pi^*\) transitions. The further inclusion of thermal motion at room temperature broadens the linewidth considerably because of variations in the molecular geometry: Transitions that had zero or negligible transition probabilities in the ground state geometry are weakly excited at room temperature.

\(^1\) Supported by Robert A. Welch Foundation

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Monday, March 5, 2007 2:30PM - 5:18PM – Session D32 DAMOP: Focus Session: Fermi Gases with Unequal Spin Populations or Masses Colorado Convention Center 402

2:30PM D32.00001 Polarized Fermi gases in an axially symmetric trap: A Bogoliubov-deGennes analysis , WILLIAM SCHNEIDER, RAJDEEP SENSARMA, MOHIT RANDERIA, The Ohio State University — We study the T=0 Fermi gas with an unequal population of up and down spins in an axially symmetric three-dimensional trap. Our motivation is to understand the differences in the experimental data from the MIT and Rice groups, which might arise from the rather different asymmetries of the trapping potentials. Using a fully self-consistent numerical solution of the Bogoliubov deGennes equations, we address the question of the validity of the local density approximation (LDA) as a function of asymmetry. We will present results for the spatial variations of the up and down densities and the superfluid order parameter as a function of polarization, trap asymmetry and interaction strength in the vicinity of unitarity.

2:42PM D32.00002 Single-plane-wave Larkin-Ovchinnikov-Fulde-Ferrell state in BCS–Bose-Einstein condensation crossover , YAN HE, CHIH-CHUN CHIEN, QIJIN CHEN, KATHY LEVIN, University of Chicago — We study the single-plane-wave Larkin-Ovchinnikov-Fulde-Ferrell (LOFF) states for BCS–Bose-Einstein condensation (BEC) crossover at general temperatures T. Because we include the important effects of noncondensed pairs, our T ≠ 0 phase diagrams are different from those reported in earlier work. We find that generalized LOFF phases may be the ground state for a wide range of (weak through moderately strong) interactions, including the unitary regime. However, these LOFF phases are readily destroyed by non-zero T. We also explore the competition between LOFF phases and phase separated states. In the cold gases, phase separation is generally the more stable, although in QCD and other applications, of LOFF physics, phase separation is not always a physical option.

cond-mat/060274
cond-mat/0608662
2:54PM D32.00003 Pairing and superfluid properties of dilute fermions with unequal masses\textsuperscript{1}, CHIEN-HUA PAO, SHIN-TZA WU. Department of Physics, Nat\'l Chung Cheng University, SUNGKIT YIP, Institute of Physics, Academia Sinica — We study the pairing between Fermions of different masses in a harmonic trap potential. Within the mean field theory, we calculate the density profiles systemically for the weak coupling BCS, the unitary limit, and the strong coupling BEC regimes. For a system with spin population imbalance, we found that the system is phase separated into concentric shells with the superfluid in the core surrounded by the normal fermion gas in both the weak-coupling BCS side and at unitary limit. In the strong-interacting regime, the composite bosons and left-over fermions can be mixed. The density profiles for unequal mass Fermions can be drastically different from their equal-mass counterparts in the unitary limit. We will discuss some possible experiments with different mass ratios which exhibit different ground state properties compared to the equal masses cases.

\textsuperscript{1}supported by NSF 95-21121-M-194-011 (Taiwan, ROC)

3:06PM D32.00004 Universal phase diagram of a strongly interacting polarized Fermi gas .

FREDERIC CHEVY. Ecole normale superieure — The recent combined theoretical and experimental breakthroughs in the field of ultra-cold Fermi systems have permitted the clarification of the ground state properties of an ensemble of attractive fermions with equal spin populations. However, many open questions remain concerning the behavior of polarized systems, where the different spin states are unequally populated. The various theoretical models imply a wide range of different scenarios and phase diagram, while two recent experiments performed at Rice and MIT present contradictory results. We will present an analysis of the ground state of an ensemble of fermions with unequal spin population in the regime of infinite scattering length. To address this problem, we will make use of universality which is characteristic of this strongly interacting regime and leads to simple scaling laws for the different physical quantities describing the system. We will in particular show that this problem is closely related to the study of an impurity imbedded in a non interacting Fermi sea of polarized atoms.

3:42PM D32.00005 Finite Temperature Effects in Trapped Unitary Fermi Gases with Population Imbalance , CHIH-CHUN CHIEN, QIJIN CHEN, YAN HE, KATHERYN LEVIN, University of Chicago — We study the finite temperature \( T \) behavior of trapped Fermi gases in the unitary regime and in the presence of a population imbalance with polarization \( p \). We obtain a phase diagram in the \( p - T \) plane, which establishes various superfluid and normal phases. Our theory, which is consistent with the standard \( T = 0 \) calculations in the literature, incorporates the important effect of non-condensed pairs. These are essential in order to arrive at physically meaningful transition temperatures \( T_c(p) \). Moreover, as a result of these non-condensed pairs our \( T \leq T_c \) profiles evolve from the well documented featureless behavior at \( p = 0 \) to behavior which shows clear indications of the presence of a condensate at \( p \neq 0 \). We also show profiles and central densities in different regimes of the phase diagram, and detailed comparisons with recent experiments are presented.


3:54PM D32.00006 Two-component Fermi system with unequal masses at unitarity: A diffusion Monte Carlo study\textsuperscript{1}, D. BLUME, Department of Physics and Astronomy, Washington State University, Pullman, WA 99164-2814, G.E. ASTRAKHARCHIK, Department de Física i Enginyeria Nuclear, Campus Nord B4-B5, Universitat Politècnica de Catalunya, E-08034 Barcelona, Spain, S. GIORGINI, Dipartimento di Fisica, Universita di Trento and BEC-INFM, I-38050 Povo, Italy — Two-component Fermi gases with varying interaction strengths have been realized in the laboratory using ultracold atoms in two different hyperfine states. In view of experimental efforts to simultaneously cool and trap two fermionic species with different masses, such as Li and K, we investigate the behavior of two-component Fermi gases with unequal masses in the strongly-interacting regime using the diffusion Monte Carlo technique. We consider mass ratios ranging from one to 100, and determine the equation of state at unitarity for a gas with identical number of “spin up” and “spin down” atoms. Furthermore, we determine the pairing gap of the system and interpret our findings.

\textsuperscript{1}This work was supported by the NSF.

4:06PM D32.00007 Two-component Fermi gas with unequal masses at unitarity: A diffusion Monte Carlo study\textsuperscript{1}, RENYUAN LIAO, KHANDKER QUADER, Department of Physics, Kent State University — Motivated by ultracold fermions, we study pairing in two-species Fermi systems with unequal population. We include both inter-species “singlet” and intra-species “triplet” pairing interactions. Using the equation of motion method, we derive two-point correlation functions, from which various physical quantities can be extracted. We self-consistently solve the resulting coupled mean-field equations for superfluid gap functions and chemical potentials, and study the effects of “triplet” correlations on various quantities at \( T = 0 \) and finite-\( T \). By imposing stability conditions, we construct a phase diagram across the BCS-BEC regimes, it is dramatically different from that without triplet correlations: the BCS singlet superfluid state can sustain a finite polarization, \( P \). For larger \( P \), we find phase separation in BCS and BEC regimes. A superfluid phase exists for all \( P \) deep in the BEC regime.

\textsuperscript{1}Partially supported by ICAM

4:18PM D32.00008 The effective Bose-Fermi scattering length in spin-polarized Fermi superfluids\textsuperscript{1}, EDWARD TAYLOR, ALLAN GRIFFIN, University of Toronto, YOJI OHASHI, Keio University — The analysis of experiments done on the BEC side of a Feshbach resonance for spin-polarized Fermi superfluids is greatly simplified by realizing that the system can be described by a Hamiltonian for a Bose-Fermi mixture, where the bosons are diatomic molecules and the fermions are the remaining unpaired atoms. To do this, however, one needs an expression for the effective boson-fermion scattering length \( a_{BF} \) that includes many-body effects which become important close to unitarity. For two-body scattering \( \text{in vacuo} \), Skorniakov and Ter-Martirosian (STM) showed in 1957 that the exact value is \( a_{BF} = 1.18a_p \), a result also obtained recently by Brodsky and coworkers using a diagrammatic approach. We derive an expression for \( a_{BF} \) in the BEC region of a spin-polarized Fermi superfluid using an alternative path-integral treatment of quartic fluctuations, which gives the essential physics of \( a_{BF} \) a simple manner and also allows us to include many-body effects. In the experimentally relevant regime outside the extreme BEC limit, we find corrections to the STM value arising from the fact that scattering occurs in a background gas of condensed Cooper pair bosons, and not in the vacuum.

\textsuperscript{1}This work was supported by NSERC of Canada and the Ministry of Education of Japan

4:30PM D32.00009 Pairing in Asymmetrical Fermi Systems with Intra- and Inter-Species Correlations\textsuperscript{1}, RENYUAN LIAO, KHANHDKER QUADER, Department of Physics, Kent State University — Motivated by ultracold fermions, we study pairing in two-species Fermi systems with unequal population. We include both inter-species “singlet” and intra-species “triplet” pairing interactions. Using the equation of motion method, we derive two-point correlation functions, from which various physical quantities can be extracted. We self-consistently solve the resulting coupled mean-field equations for superfluid gap functions and chemical potentials, and study the effects of “triplet” correlations on various quantities at \( T = 0 \) and finite-\( T \). By imposing stability conditions, we construct a phase diagram across the BCS-BEC regimes, it is dramatically different from that without triplet correlations: the BCS singlet superfluid state can sustain a finite polarization, \( P \). For larger \( P \), we find phase separation in BCS and BEC regimes. A superfluid phase exists for all \( P \) deep in the BEC regime.

\textsuperscript{1}Partially supported by ICAM
We acknowledge funding from NSF, NASA, and NIST.

We gratefully acknowledge the National Science Foundation for support.

We acknowledge funding from NSF, NASA, and NIST.
9:00AM H32.00006 Phase separation in a mixture of two species of fermionic atoms in one-dimensional optical lattice. SHI-JIAN GU, RUI FAN, HAI-QING LIN, The Department of Physics, The Chinese University of Hong Kong — In this work, we study the ground-state phase diagram of a mixture of two species of fermionic atoms in one-dimensional optical lattice, as described by an asymmetric Hubbard model. We investigate the quantum phase transition from density wave to phase separation by studying both the corresponding charge order parameter and quantum entanglement, and present phase diagram as function of band-filling. A rigorous prove, that even for the case of a single hole doping, the density wave is unstable to the phase separation in the infinite U limit, will be presented. We also discuss experimental feasibility of observing such a phase separation.

9:12AM H32.00007 Natural orbits of atomic Cooper pairs in a nonuniform Fermi gas. Y.H. PONG, C.K. LAW, Department of Physics and Institute of Theoretical Physics, The Chinese University of Hong Kong, Shatin, Hong Kong SAR, China — We present the natural orbits of atomic Cooper pairs in an inhomogeneous Fermi gas. These orbits provide the pairing mode functions of constructing BCS states in finite systems. We further exploit such orbits to study Cooper pair wave functions in various trapping situations. In particular, we quantify and characterize the quantum entanglement between atoms in a Cooper pair associated with the spatial degrees of freedom. (Reference : Y.H. Pong, C.K. Law, Phy. Rev. A 74, 013618 (2006))

9:18AM H32.00008 Spontaneous Magnetization of Harmonically Trapped Ultracold Fermions in an Optical Lattice. R.C. BROWN, L.D. CARR, Physics Department, Colorado School of Mines, Golden, Colorado 80401, USA, I. DANSHITA, J.E. WILLIAMS, CHARLES W. CLARK, Electronic and Optical Physics Division, National Institute of Standards and Technology, Gaithersburg, Maryland 20899, USA — We use a single-band Fermi Hubbard Hamiltonian to study the ground states of a system of ultracold fermions in a one dimensional optical lattice with an external harmonic trap. We perform simulations using exact diagonalization for small systems with one to five wells and we employ Vidal’s algorithm (Time Evolving Block Decimation) for larger systems with up to a hundred wells. As the trapping frequency increases we observe spontaneous transverse magnetization at the edges of the trap. We present a theoretical interpretation of this intriguing result, and discuss how it can be observed in experiments.

9:36AM H32.00009 Spin Drag and Spin-Charge Separation in Cold Fermi Gases. MARCO POLINI, NEST-CNRS-INFM and Scuola Normale Superiore, I-56126 Pisa, Italy, GIOVANNI VIGNALE, Department of Physics and Astronomy, University of Missouri, Columbia, Missouri 65211, USA — Low-energy spin and charge excitations of one-dimensional interacting fermions are completely decoupled and propagate with different velocities. These modes however do not live forever and can decay due to several possible mechanisms, even in the complete absence of impurities. In the spin channel the main mechanism of decay at finite temperature is related to a distinctive mechanism of friction that dominates spin transport: the spin drag. In this work we show how two component cold Fermi gases confined inside a tight atomic waveguide offer the unique opportunity to measure directly the spin-drug relaxation time that controls the broadening of a spin packet.

10:00AM H32.00011 Pairing with multiple flavors of fermions in ultracold atoms. ROBERT CHERNG, Harvard University, GIL REFAEL, California Institute of Technology, EUGENE DEMLER, Harvard University — We use Ginsburg-Landau formalism to discuss s-wave pairing in ultracold Fermi gases with N flavors and with SU(N) symmetric interactions. We show that when the number of flavors is greater than two, the uniform superfluid state is unstable since the magnetization or flavor imbalance couples directly to the superfluid order parameter. We study the case of three flavors in detail to analyze the competition between phase separation and non-uniform FFLO-like superfluid states. Implications of our results for experiments will be discussed.

9:48AM H32.00010 Dynamics of particle density and noise correlators of a cold Fermi system expanding from a harmonic trap. PAVEL NAGORNYYKH, VICTOR GALITSKI, Joint Quantum Institute and Physics Department, University of Maryland, College Park — We have studied dynamics of an atomic Fermi system with a finite number of particles \( N \) after it is released from a harmonic trapping potential. We consider two different initial states: the Fermi sea state and the projected BCS (PBCS) state described by the projection of the grand-canonical BCS wave function onto the subspace with a fixed number of particles. In the former case, we derive exact and simple analytic expressions for the particle density \( n(r, t) \) and density-density correlation functions \( \langle n(r, t)n(r', t) \rangle \) taking into account the level quantization and possible anisotropy of the trap. In the latter case of the PBCS state, we obtain analytic expressions for the density and its correlators in the leading order with respect to the ratio of the trap frequency and the superconducting gap (the ratio assumed small). We discuss several interesting dynamic features, which may be used to distinguish between the Fermi sea and BCS states.

10:00AM H32.00012 Two-species fermion mixtures with mass and population imbalance. MENDERES ISKIN, CARLOS SA DE MELO, Georgia Institute of Technology — We analyze the phase diagram of uniform superfluidity for two-species fermion mixtures from the Bardeen-Cooper-Schrieffer (BCS) to Bose-Einstein condensation (BEC) limit as a function of the scattering parameter and population imbalance. We find at zero temperature that the phase diagram of uniform superfluidity versus scattering parameter is asymmetric for unequal masses, having a larger stability region for uniform superfluidity when the lighter fermions are in excess. In addition, we find topological quantum phase transitions associated with the disappearance or appearance of momentum space regions of zero quasiparticle energies. Lastly, near the critical temperature, we derive the Ginsburg-Landau equation, and show that it describes a dilute mixture of composite bosons and unpaired fermions in the BEC limit.
11:27AM J32.00002 Interfacing Collective Atomic Excitations and Single Photons, JONATHAN SIMON, HARUKA TANJI, JAMES THOMPSON, VLADAN VULETIC, MIT/Harvard Center for Ultracold Atoms — A variety of quantum communication and computing schemes rely on the storage and transfer of single photonic excitations. We demonstrate generation, storage, and adiabatic transfer of such excitations, using ensembles of Cs atoms within a low finesse optical resonator as a storage medium. We explore theoretical and practical limitations on read-out, experimentally realizing a peak atomic-photonic conversion efficiency of 0.84 (11). The storage in the system exhibits two doppler times, which can be understood in terms of long- and short- wavelength spin gratings simultaneously written into the atomic ensemble. We demonstrate cavity mediated transfer of a quantized atomic excitation between atomic ensembles within the same optical resonator. These results pave the way towards a practical single photon generation and storage apparatus, useful in quantum communication, computation, and beyond. This work was supported in parts by the NSF, DARPA, and ARO.

11:39AM J32.00003 Anyonic Braiding in Optical Lattices1, CHUANWEI ZHANG, VITO SCAROLA, SUMANTA TEWARI, SANKAR DAS SARMA, CMTC, Department of Physics, University of Maryland, College Park, MD 20742 — Topological quantum computation proposes to use braiding of collective excitations imprinted in topologically protected coherent quantum states of many particles, as opposed to a single particle, to aid in or even perform quantum computation. Here we explicitly work out a realistic experimental scheme to create, braid and detect topological excitations in the Kitaev model built on a tunable robust system, a cold atom optical lattice. A key feature of topological excitations is their braiding statistics, how they behave when one excitation is taken around another. An observation of the non-trivial braiding statistics described in this Report would directly establish the existence of anyons, quantum particles which are neither fermions nor bosons. Demonstrating anyonic braiding statistics is tantamount to observing a new form of matter, topological matter. Once created, excitations in quantum topological matter, as opposed to dedicate single particle quantum states, can provide a robust way to encode and manipulate quantum information.

1This work is supported by ARO-DTO, ARO-LPS, and NSF.

11:51AM J32.00004 Turning back time in the optical lattice: How to measure the fidelity of a quantum simulation., FERNANDO CUCCHIETTI, Los Alamos National Lab. — I show how to perform a Loschmidt echo (time reversal) in the Bose-Hubbard model implemented with cold bosonic atoms in an optical lattice. The echo is obtained by applying a linear phase imprint on the lattice and a change in magnetic field to tune the boson-boson scattering length through a Feshbach resonance. I discuss how the echo can measure the fidelity of the quantum simulation, and also the intensity of an external potential (e.g. gravity), or the critical point of the superfluid-insulator quantum phase transition.

12:03PM J32.00005 Characterization of scalable ion traps for quantum computation1, R.J. EPSTEIN, J.I. BOLLINGER, D. LEIBFRIED, S. SEIDELIN, J. BRITTON, J.H. WESENBERG, N. SHIGA, J.M. AMINI, R.B. BLAKEYSTAD, K.R. BROWN, J.P. HOME, W.M. ITANO, J.D. JOST, C. LANGER, R. OZERI, D.J. WINELAND, NIST, Boulder, Colorado 80305, USA — We discuss the experimental characterization of several scalable ion trap architectures for quantum information processing. We have developed an apparatus for testing planar ion trap circuits which features: a standard chip carrier for ease of interchanging traps, a single laser Raman cooling scheme, and photo-ionization loading of Mg+ ions. The primary benchmark for a given trap is the heating rate of the ion motional degrees of freedom, which can reduce multi-ion quantum gate fidelities. An important aspect of the experiments is the demonstration that a microfabricated trap is capable of storing high-fidelity qubits. The experiments should be extended to the characterization of planar intersecting trapping zones for versatile ion choreography. With the recent ability to fabricate planar traps with sufficiently low heating rates for quantum computation2, we describe current results on the simulation and fabrication of planar traps with multiple intersecting trapping zones for versatile ion choreography.

2Work supported by DTO and NIST.


12:15PM J32.00006 Entangling operations and rapid measurement of clock-state qubits in Yb or Sr for quantum information processing, RENE STOCK, NATHAN S. BABCOCK, BARRY C. SANDERS, Institute for Quantum Information Science, University of Calgary — The optical clock-transitions in Yb and Sr are prime candidates for encoding qubits for quantum information processing applications. Electric dipole one- and two-photon transitions between the long-lived 1S0 and 3P0 states are angular momentum and parity forbidden, respectively. This results in a highly desirable low decoherence rate. In this work, we investigate the challenges involved in using these prime candidates. We devise entangling operations for Yb and Sr atoms trapped in optical microtraps, as well as determine the feasibility of rapid qubit rotation and measurement of qubits encoded in this desirable low-decoherence clock transition. We propose ultracold collisions for entangling operations and a recoil-free three-photon transition1 for fast rotation of qubits, followed by ultrafast readout via resonant multiphoton ionization. The rapid control of atomic qubits is crucial for high-speed synchronization of quantum information processors, but is also of interest for tests of Bell inequalities. We investigate rapid measurement of clock-state qubits in the context of a Bell inequality test that avoids the detection loophole in spacelike separated entangled qubits. [1] T. Hong, C. Cramer, W. Nagourney, E. N. Fortson, Phys. Rev. Lett. 94, 050801 (2005).

12:27PM J32.00007 Quantum spin relaxation in mixtures of spinor cold atoms, YI-YA TIAN, PO-CHUNG CHEN, DAW-WEI WANG, National Tsing-Hau University — Recently spin relaxation becomes an extensively studied subject in the field of spinor photons. One of the most important mechanism of electron spin relaxation in a semiconductor laser is the electron spin dephasing due to the hyperfine interaction of the electron and nuclear spins. Due to limitations in solid state experiments, the effects of nuclear spins to the electron spin relaxation is still not fully understood yet. Here we propose that such electron-nuclei system can be modeled by a mixture of two species of spinor cold atoms (say 7Li and 87Rb), loaded in a bi-frequency optical lattices of large wavelength difference. We use exactly diagonalization method to study how an initially spin polarized “electron” atom relaxs in a spin bath of “nuclei” atoms. Our calculation shows that the spin relaxation are strongly sensitive to the polarization of “nuclei” atoms, while for the fully unpolarized case the relaxation is mainly determined by the density of states. Our theoretical results can be also applied in studying the electron spin relaxation dynamics in the solid state quantum qubit.

12:39PM J32.00008 Microfabricated surface-electrode ion traps for scalable quantum information processing1, SIGNE SEIDELIN, JOE BRITTON, JOHN CHIAVERINI, RAINER REICHELE, JOHN BOLLINGER, DIDI LEIBFRIED, JANUS WESENBERG, BRAD BLAKEYSTAD, RYAN AMINI, JASON BRITTON, KENTON BROWN, JOHNATHAN HOME, DAVID HUME, NOBU SHIGA, WAYNE ITANO, JOHN JOST, EMMANUEL KNILL, CHRIS LANGER, ROEE OZERI, DAVID WINELAND, NIST — We confine individual atomic ions in an rf Paul trap with a novel geometry where the electrodes are located in a single plane and the ions confined above this plane1,2,3. This device is realized with simple microfabrication techniques: using ensembles of Cs atoms within the same optical resonator. These results pave the way towards a practical single photon generation and storage apparatus, useful in quantum communication, computation, and beyond. This work was supported in parts by the NSF, DARPA, and ARO.

1SS acknowledges the Carlsberg Foundation. Work supported by the DTO and NIST.


12:51PM J32.00009 A Point Paul Trap for Quantum Information Experiments, ROBERT CLARK, LI YANG, ISAAC CHUANG, Massachusetts Institute of Technology — The point Paul trap is a surface electrode ion trap that provides three-dimensional confinement using a single radiofrequency ring electrode, with ground inside and outside. Such a trap may have applications in the development of ion trap lattices for quantum simulation and quantum computation, and has previously been demonstrated using charged microspheres. Here we present a point trap for strontium ions with a ring radius of 1.6 mm and a ring width of .3 mm, consisting of gold electrodes on a laminate substrate and loaded by laser ablation.

Typical operating parameters are a trap depth of .8 eV and secular frequencies of 250 kHz, for a trap drive of 800 V at 2.5 MHz. Numerical models of the trap are compared to experimentally measured motional secular frequencies of the ions, and the efficiency of laser ablation loading as a function of trap depth is studied. An experiment to measure the heating rate of a single ion as a function of height in the trap is also discussed.

1:03PM J32.00010 Optical MEMS Based Beam Steering for 2D lattice, CABLEN KNOERNSCHILD, CHANGSOON KIM, FELIX LU, BIN LIU, JUNGSANG KIM — Most scalable quantum computation approaches using arrays of trapped ions or individual neutral atoms in optical lattices require the experimental capability to address individual qubits in the large array. It is difficult to achieve such flexibility with traditional optical systems utilizing bulky components aligned on optical tables. Optical micro-机电mechanical systems (MEMS) technology can provide a flexible and scalable solution for this functionality. We have developed simple beam steering optics using controllable MEMS mirrors that enable one laser beam to address multiple qubit locations in a linear trap or 2D trap lattice. The system can individually address 25 different positions on a 5 × 5 square array. MEMS mirror settling times of < 5μs were demonstrated which allow for fast access time between qubits. Characterization of beam quality and optical power throughput is also presented. This system has the advantage of providing multiple individually addressed spots of different colors simultaneously without any frequency shifts.

1:15PM J32.00011 surface-electrode ion trap loaded by laser ablation, PAUL ANTOHI, WASEEM BAKR, ISAAC CHUANG, JAROSLAW LABAZIEWICZ, KEN BROWN, MIT — traps operated at liquid helium temperatures offer many advantages for exploring new physics, such as quantum interactions between ions and superconductors; cooling may also reduce anomalously high ion heating rates currently observed and attributed to surface charge fluctuations. However, cryogenic traps are traditionally experimentally challenging to realize, due to the careful attention required to thermally anchor the trap, and due to the incompatibility of standard high-temperature ion sources with a cryogenic environment. We demonstrate a new approach to these challenges using a millimeter scale printed-circuit board trap with surface electrode geometry. The trap is operated in a liquid helium bath cryostat, and a trap and cool strontium 88 ions. The planar aspect of this trap simplifies anchoring to the helium baseplate, and provides clear access for loading ions from an ablation plume produced by < 7 mJ pulses of a Q-switched Nd-YAG laser incident on a Sr/Al alloy target. We are able to load traps with depths as low as 0.7 eV, and with laser cooling we observe small ion crystals with between one and twenty six optically resolved ions, with individual ion lifetimes averaging 2 hours. Initial estimates based on the observed residual gas collision rates are consistent with a vacuum pressure below 10^-9 torr, and the true pressure is likely much lower.

1:27PM J32.00012 Sideband cooling and anomalous heating of trapped Sr\(^+\) ion, JAROSLAW LABAZIEWICZ, YUFEI GE, PAUL ANTOHI, ISAAC CHUANG, Center for Ultracold Atoms, MIT — Many schemes for entangling and quantum processing with trapped ions require cooling the ions close to motional ground state, and the anomalous heating of the ion can be the limiting factor in gate fidelity. We developed a simple laser system, based on external cavity diode lasers with optical feedback to a running-wave cavity to investigate this heating. Without the use of a high finesse cavity, or fast active feedback, we have achieved < 30 kHz linewidths and ≈ 1 MHz long term stability. This system was used to sideband cool a single Sr\(^+\) ion to a motional ground state with > 90% probability and observe Rabi oscillations on the 5S\(_{1/2}\) → 4P\(_{3/2}\) transition. We present our results on heating and cooling rates of the ion in room temperature and cryogenic ion traps.

1:39PM J32.00013 One-way quantum computing in optical lattices with many atom measurements, TIMOTHY P. FRIESEN, DAVID L. FEDER, University of Calgary — In one-way quantum computation single qubit measurements on a highly entangled state, known as a cluster state, are sufficient to perform universal quantum computation. One of the most promising approaches for generating the cluster state is to manipulate ultracold atoms in optical lattices. Unfortunately, the small lattice spacing places severe constraints on the ability to sequentially measure the states of individual atoms by external lasers, a crucial requirement for one-way computing. With current technology, we are generally limited to many atom measurements. We have developed a deterministic protocol for one-way quantum computing based on many atom measurements on an optical lattice cluster state, requiring only polynomial classical overhead. Our scheme opens the way toward concrete experimental quantum computing in neutral atom systems.

Tuesday, March 6, 2007 2:30PM - 5:30PM –
Session L32 DAMOP: Focus Session: BEC/BCS Crossover Colorado Convention Center 402

2:30PM L32.00001 Large N expansion for superfluid Fermi gases at unitarity, MARTIN Y. VEILLETTE, University of Colorado, DANIEL E. SHEEHY, Iowa State University, LEO RADZIHOVSKY, University of Colorado — We study an s-wave resonant Fermi gas near the unitarity point. We treat this problem by generalizing the Fermi gas to a model with 2D hyperfine states (with Sp(2N) symmetry). We show that for N = ∞, the model can be solved exactly by the BEC-BCS mean field solution. In order to address the physically relevant problem (N = 1), we perform a systematic 1/N loop expansion around the BEC-BCS solution. For N = 1, we obtain a variety of thermodynamic quantities, including the energy, the pairing gap, and the upper critical polarization. We compare our results to experimental data and other theoretical approaches.
the C/k exact of energy during a real-time ramp of the scattering length, and the energy spectrum of such a Fermi gas satisfy a few simple universal regime in which the interaction is described by a single parameter, a

Bose and Fermi gases can be described to a very good approximation by a single atomic physics parameter, the s

interfermionic forces have a range much shorter than the average interparticle spacing, the characteristic de Broglie wavelength, and

1

ing Length

[1] V. Akkineni, N. Trivedi, D.M. Ceperley, cond-mat/0608154

Tc 0.24 Ef from a finite size scaling analysis of the superfluid density. The pseudogap phase is characterised by the spin susceptibility and compressibility. We identify the pseudogap crossover temperature scale T* 0.70 Ef below which pairing correlations develop. We estimate the critical temperature for condensation simulations and tested against previous ground-state Quantum Monte Carlo calculations. From the growth of the density correlations for unequal spins, we interactions tuned to the unitarity point [1]. The finite temperature, non-perturbative, Restricted Path Integral Monte Carlo (R-PIMC) method is used for our simulations and tested against previous ground-state Quantum Monte Carlo calculations. From the growth of the density correlations for unequal spins, we identify the pseudogap crossover temperature scale T* 0.70 Ef below which pairing correlations develop. We estimate the critical temperature for condensation Tc 0.24 Ef from a finite size scaling analysis of the superfluid density. The pseudogap phase is characterised by the spin susceptibility and compressibility. We will also present results for unequal populations of fermions.

In collaboration with V. Akkineni and D.M. Ceperley.

3:42PM L32.00005 Exact Relations for A Strongly-Correlated Fermi Gas With Large Scattering Length1. SHINA TAN, INT, Univ of Washington — A 2-component Fermi gas with a large and tunable scattering length a is considered. If the interfermionic forces have a range much shorter than the average interparticle spacing, the characteristic de Broglie wavelength, and |a|, the system is in a universal regime in which the interaction is described by a single parameter, a. We show that the energy, the momentum distribution, the pressure, the change of energy during a real-time ramp of the scattering length, and the energy spectrum of such a Fermi gas satisfy a few simple exact relations. The importance of the C/k4 tails of the momentum distributions at large k is stressed. Implications of these results for experiments on ultracold atomic Fermi gases near Feshbach resonances are discussed.

3:54PM L32.00006 Dilute Bose and Fermi gases with large generalized scattering lengths1. RYAN M. KALAS, D. BLUME, Department of Physics and Astronomy, Washington State University, Pullman, Washington 99164-2814 — Dilute weakly-interacting Bose and Fermi gases can be described to a very good approximation by a single atomic physics parameter, the s-wave scattering length. Utilizing broad Feshbach resonances, strongly-interacting two-component Fermi gases with infinitely large interspecies scattering lengths can now be studied experimentally. In this so-called unitary regime, the only remaining energy scale is the energy EFG of the non-interacting Fermi gas, and it has been shown that the energy of the Fermi gas becomes 0.14EFG. We investigate Bose and Fermi gases with non-vanishing angular momentum using the lowest order constrained variational method. In particular, we focus on the regime where the generalized scattering length becomes infinite. For example, we show that the energy of d-wave interacting fermions depends not only on EFG but additionally on an energy scale set by the range of the underlying two-body potential.

In collaboration with V. Akkineni and D.M. Ceperley.

4:06PM L32.00007 Luttinger theorem and Fermi liquid behavior close to a Feshbach resonance. SERGIO GAUDIO, Department of Physics, Boston College and Universita’ La Sapienza, Roma, JASON JACKIEWICZ, Max Planck Institute, Katlenburg-Lindau, Germany, KEVIN BEDELL, Department of Physics, Boston College — Based on the results obtained in a previous paper , we derive the thermodynamic properties of a Fermi gas, deep into the quantum degenerate regime and provide a useful test for the validity of Luttinger theorem. We show that, if Luttinger theorem holds, a first order phase transition has to occur in the normal phase as a function of the interaction strength, U, as a consequence of a jump occurring in the compressibility, spin susceptibility and specific heat. The signature of the transition is given by the presence of a non-zero latent heat. We also show that a volume change occurs at finite temperatures from the BEC to the BCS side of the Feshbach resonance, in the normal phase. The transition has an end point close to the BCS critical temperature. Thus, observation of these properties will require suppression of the superfluid phase. Also we demonstrate that a paramagnetic system in equilibrium, close to a diverging scattering length, expels any applied magnetic field and as a consequence, there is no Clogston limit in the in the superfluid phase.

4:18PM L32.00008 Collisional hydrodynamic mode frequencies in the BCS-BEC crossover near unitarity1. ALLAN GRIFFIN, EDWARD TAYLOR, University of Toronto — In the collisional region at finite temperatures (produced by the large value of the s-wave scattering length), the collective modes of a superfluid Fermi gas are expected to be described by the Landau two-fluid hydrodynamic equations. These equations predict two types of modes: an in-phase oscillation of the normal and superfluid components as well as an out-of-phase oscillation. We prove that at unitarity and at all temperatures, the in-phase breathing mode solution of the two-fluid equations has a frequency identical to that calculated at T = 0 by Cozzini and Stringari. This temperature-independence has been verified in recent experiments by Thomas and coworkers. For the special case of an isotropic trap, we find the temperature-independent frequency \omega = 2\omega_0, a result predicted to be valid under all conditions at unitarity by Castin. We also discuss the more interesting finite-T out-of-phase (the analogue of second sound) breathing mode frequency given by the Landau-two-fluid equations at unitarity.

This work was supported by NSERC of Canada.
4:30PM L32.00009  Suppression of $T_c$ by Medium Effects from Dilute to Dense Regime: A Crossing-symmetric Approach

1. KHANDKER QUADER, RENYUAN LIAO, Department of Physics, Kent State University — We study medium effects on superfluid transition temperature of 1- and 2-component strongly correlated Fermi systems. A crossing-symmetric approach allows us to explore this across dilute and dense regimes within a single framework. We include many-body effects such as density, spin-density, and current fluctuations. Pairing interactions are deduced from scattering amplitudes in the pairing channel. For 2-component systems, we find the known factor-of-2 suppression in $T_c$ to be robust across both regimes, except near the unitarity limit, where the suppression is more pronounced. For the 1-component case, the suppression can be greater, and not universal across the regimes. We discuss possible physical causes for the $T_c$ suppression.

1Partially supported by ICAM

4:42PM L32.00010  Quantum fluctuations in the superfluid state of the BCS-BEC crossover

RAJDEEP SENSARMA, ROBERTO DIENER, MOHIT RANDERIA, The Ohio State University — While the Leggett-BCS mean-field approach gives a reasonable zeroth order description of the superfluid ground state in the BCS-BEC crossover, there are many ways in which it is inadequate. In addition to quantitative discrepancies with quantum Monte Carlo and experimental results at unitarity and with exact results for dimer-dimer scattering in the BEC limit, the mean field theory also misses the qualitative effects of quantum depletion of the condensate in a strongly interacting Fermi system. To address these concerns, we include the effects of zero-point motion of collective excitations and of the pair continuum in calculating various ground state properties. We implement this RPA in a functional integral formalism which ensures that the feedback of the collective modes on the saddle point respects Goldstone’s theorem. We will present results on the ground state energy, gap, compressibility and collective mode frequency as a function of $1/k_F$.

4:54PM L32.00011  The universal phase diagram of fermionic quantum liquids near the unitarity limit

PREDRAG NIKOLIC, SUBIR SACHDEV, Harvard University — We consider several models of particles with short-range attractive interactions whose universal properties are controlled by an unstable renormalization-group fixed point at zero density and temperature. The fixed point corresponds to the Feshbach resonance, and relevant perturbations are the detuning of the resonance, and parameters that control the particle densities. Some critical exponents are determined exactly as expansions about two and four spatial dimensions. The existence of a renormalization-group fixed point implies a universal phase diagram as a function of density, temperature, population imbalance, and detuning. We study this phase diagram in the context of BEC-BEC crossover of s-wave paired fermions. We develop a 1/N expansion, based upon models with $Sp(2N)$ symmetry, and use it to systematically analyze the universal properties of interacting fermions near the unitarity limit. This approach overcomes several limitations of the expansions about two and four dimensions, and allows a well-controlled exploration of the full phase diagram of imbalanced fermion populations in the experimentally relevant three-dimensional space.

5:06PM L32.00012  Properties and dynamics of four particles in a trap in the BCS-BEC crossover.

1. JAVIER VON STECHER, CHRIS H. GREENE, JILA and Department of Physics, University of Colorado, Boulder, Colorado 80309-0440 — The Hamiltonian of two spin up and two spin down fermions in a trap is calculated using a correlated gaussian basis in the vicinity of the BCS-BEC crossover. From the spectrum, key properties of the few-body system are deduced as a function of the 2-body scattering length. After a diabatization procedure, the wavefunctions are used to evolve in time in an initial configuration, mimicking molecule formation experiments with Fermi gases in the BCS-BEC crossover. The dynamics are successfully modelled as a sequence of Landau-Zener transitions. Finally, atom-molecule coherent quantum beats in this system are studied and a ramping scheme is proposed for experimental investigation.

1This work was supported in part by NSF.

5:18PM L32.00013  Describing the degenerate Fermi in a renormalized hyperspherical treatment

1. SETH T. RITTENHOUSE, JAVIER VON STECHER, CHRIS H. GREENE, Department of Physics and JILA, University of Colorado, Boulder CO 80309-0440 — We describe the degenerate Fermi gas with zero-range density-dependent renormalized interactions (eprint cond-mat/0610848) in an isotropic trap using a variational hyperspherical approach. This method reduces the complex many body Hamiltonian to a simple one-dimensional effective potential in a collective coordinate, the hyperradius, which can be thought of as the rms size of the gas. Exploring the behavior of the effective potential in the unitarity region where the two-body scattering length becomes very large and negative produces interesting effects. The low energy collective excitation frequency of a two spin component gas approaches the noninteracting frequency, as has been seen in hydrodynamic treatments. For larger numbers of spin components an interesting dynamical instability develops.

1This work was supported by funding from the NSF.

Wednesday, March 7, 2007 8:00AM - 11:00AM — Session N3 DAMOP: Frontiers in Ultra-cold Gases in Optical Lattices Colorado Convention Center Korbel 2A-3A

8:00AM N3.00001  Evidence for Superfluidity of Ultracold Fermions in an Optical Lattice

YINGMEI LIU, MIT-Harvard Center for Ultracold Atoms, and Research Laboratory of Electronics, Massachusetts Institute of Technology — The study of superfluid fermion pairs in a periodic potential has important ramifications for understanding superconductivity in crystalline materials. By using cold atomic gases, various models of condensed matter can be studied in a highly controllable environment. Weakly repulsive fermions in an optical lattice could undergo d-wave pairing at low temperatures, a possible mechanism for high temperature superconductivity in the copper oxides. The lattice potential could also strongly increase the critical temperature for s-wave superfluidity. Recent experimental advances in bulk atomic gases include the observation of fermion-pair condensates and high-temperature superfluidity. Experiments with fermions and bosonic bound pairs in optical lattices have been reported but have not yet addressed superfluid behavior. Here we report the observation of distinct interference peaks when a condensate of fermionic atom pairs is released from an optical lattice, and high-temperature superfluidity. Experiments with fermions and bosonic bound pairs in optical lattices have been reported but have not yet addressed superfluid behavior. Such strongly interacting fermions in an optical lattice can be used to study a new class of hamiltonians with interband and atom-molecule couplings.

1In collaboration with J. K. Chin, D. Miller, C. Stan, W. Setiawan, C. Sanner, K. Xu and W. Ketterle, Department of Physics, MIT-Harvard Center for Ultracold Atoms, and Research Laboratory of Electronics, Massachusetts Institute of Technology.
at room temperature. We improve by up to two orders of magnitude the uncertainties in the absolute optical frequency and hyperfine structure of the Department of Physics, University of Notre Dame, SCOTT A. DIDDAMS, LEO HOLLBERG, Time and Frequency Division, National Institute of Standards with a femtosecond frequency comb, VELA L. MBELE, CSIR-NML, 1 Meireng Naude Street, Pretoria, 0001, RSA, JASON E.

For the NIST fountain, comparisons have been conducted for six years, while comparisons with fountains at PTB, BNM-SYRTE, and INRM have been reliably conducted for almost three years. During this time the sun's gravitational potential changes due to earth's orbital eccentricity \( e \), with an amplitude given by \( \Delta \phi/e \approx GM_{\odot} e/\alpha(\text{au})^2 \approx 1.66 \times 10^{-10} \), where \( \alpha \) is the earth’s orbital semimajor axis. The Cs-H maser comparisons show no correlation with variations in the solar potential, within an uncertainty that is about 30 times smaller than the previous most sensitive comparisons.

9:48AM N3.00004 2-D Lattices at JILA, ERIC CORNELL, NIST and JILA — I will discuss recent developments in our work on 2-D optical lattices at JILA, in particular the interaction of vortices with a lattice, and the effects of finite-T fluctuations.

10:24AM N3.00005 Normal State of a Polarized Fermi Gas at Unitarity, CARLOS LOBO, BEC-INFM Center, University of Trento — I will discuss the Fermi gas at unitarity and at \( T=0 \) by assuming that, at high polarizations, it is a normal Fermi liquid composed of weakly interacting quasiparticles associated with the minority spin atoms. I will show that a quantum Monte Carlo approach can be used to calculate their effective mass and binding energy, as well as the full equation of state of the normal phase as a function of the concentration of minority atoms. We predict a first order phase transition from normal to superfluid at a concentration of 0.44 corresponding, in the presence of harmonic trapping, to a critical polarization of 77 per cent. I will discuss radii and the density profiles of both spin components in the trap and our prediction that the frequency of the spin dipole mode will be increased by a factor of 1.23 due to interactions.

Wednesday, March 7, 2007 8:00AM - 11:00AM — Session N32 DAMOP: Casimir Forces, Precision Measurements, and Fundamental AMO Interactions Colorado Convention Center 402

8:00AM N32.00001 An Electron EDM Search Using Trapped Molecular Ions, LAURA SINCLAIR, JOHN BOHN, AARON LEANHARDT, EDMUND MEYER, RUSSELL STUTZ, ERIC CORNELL, JILA, NIST, and the Department of Physics, University of Colorado, Boulder, CO 80309 USA — A sample of trapped molecular ions offers unique possibilities to search for a permanent electron electric dipole moment (EDM). Specifically, we plan to perform this search using the unpaired electron spins in the \(^3\text{D}_2\) state of trapped \(^{15}\text{HfF}^+\) molecular ions. Ions are easy to trap which will provide the long coherence times necessary to measure the small energy differences associated with an electron EDM. Additionally, the internal electric fields in polarized diatomic molecules can exceed \(10^{10}\) V/cm, which will amplify any EDM induced energy splittings. We have created \(^{15}\text{HfF}^+\) ions in a supersonic expansion jet by ablating a Hf target with a pulsed Nd:YAG laser in a \(\text{He} + 1\%\text{SF}_6\) environment. The chemical reaction \(^{15}\text{Hf}^+ + \text{SF}_6 \rightarrow ^{15}\text{HfF}^+ + \text{SF}_5\) is exothermic and proceeds rapidly. The He buffer gas in the expansion cools the molecular translational, vibrational, and rotational degrees of freedom to \(10^{-3}\) K. We have measured these temperatures via laser induced fluorescence spectroscopy on known neutral Hf atomic lines and newly identified neutral Hf molecular lines, and are currently searching for the unknown HfF molecular lines.

8:12AM N32.00002 Testing local position invariance with four Cesium primary frequency standards and four NIST Hydrogen masers, NEIL ASHBY, Dept. of Physics, University of Colorado, Boulder, CO 80309, THOMAS HEAVNER, STEVEN JEFFERTS, THOMAS PARKER, National Institute of Standards and Technology, Boulder, CO 80309 — In General Relativity, Local Position Invariance (LPI) implies that if atomic clocks of different structure are placed together and synchronized at a particular location, they will remain synchronized while they move through a variable gravitational potential. In this work we compare four active Hydrogen masers located at the National Institute of Standards and Technology (NIST) with Cesium fountain primary frequency standards at NIST, Physikalische-Technische Bundesanstalt (PTB, Germany), Bureau National de Met´erie Syst`emes de R´ef´erence Temps Espace (BNM-SYRTE, France) and Istituto Nazionale di Ricerca Metrologica (INRMI, ITALY). For the NIST fountain, comparisons have been conducted for six years, while comparisons with fountains at PTB, BNM-SYRTE, and INRMI have been reliably conducted for almost three years. During this time the sun’s gravitational potential \( \Phi \) changes due to earth’s orbital eccentricity \( e \), with an amplitude given by \( \Delta \Phi/e \approx GM_{\odot} e/\alpha(\text{au})^2 \approx 1.66 \times 10^{-10} \), where \( \alpha \) is the earth’s orbital semimajor axis. The Cs-H maser comparisons show no correlation with variations in the solar potential, within an uncertainty that is about 30 times smaller than the previous most sensitive comparisons.

8:24AM N32.00003 Absolute optical frequency measurements of Cs two-photon transitions with a femtosecond frequency comb, VELA L. MBELE, CSIR-NML, 1 Meireng Naude Street, Pretoria, 0001, RSA. JASON E. STALNAKES, VLADISLAV GERGINOV, TARA FORTIER, Time and Frequency Division, National Institute of Standards and Technology, CAROL E. TANNER, Department of Physics, University of Notre Dame, SCOTT A. DIDDAMS, LEO HOLLBERG, Time and Frequency Division, National Institute of Standards and Technology — We study by direct excitation with a mode-locked femtosecond optical frequency comb, multiple transitions in Cs atoms in a vapor cell at room temperature. We improve by up to two orders of magnitude the uncertainties in the absolute optical frequency and hyperfine structure of the \( ^2S_{1/2} \rightarrow ^2P_{3/2} \) and \( ^2P_{5/2} \) transitions in \(^{133}\text{Cs}\). Cesium is one of the well studied heavy atoms, with atomic structure calculations on the order of 1%, and has provided a fertile testbed for fundamental tests of atomic theory and QED. This work reports on a simple and novel experimental approach that allows simultaneous recording of multiple transition frequencies. Atoms in a vapor cell at room temperature have a broad Doppler velocity distribution which allow selective excitation by discrete modes of a mode-locked femtosecond comb. This, in turn, results in stepwise multiphoton resonant transitions in the atoms. We model the collected spectra using a standard \( 2\gamma \) formula and use least square fitting routines to extract improved values of absolute optical frequencies and coupling constants.
8:36AM N32.00004 Rb Magnetic Resonance Near Coated Glass Surfaces in an Inhomogeneous Field1, KAI FENG ZHAO, M. SCHADEN, Z. WU, Rutgers University - Newark — Evanescent waves are used to measure the rf magnetic resonance signal of Rb spin polarization near Pyrex glass surfaces coated with anti-relaxation coatings in an inhomogeneous magnetic field. The signal shows an asymmetric line shape, with one side having approximately Lorentzian profile and the other side being inhomogeneously broadened. The origin of this asymmetry is due to the diffusion of spins. We studied its dependence on buffer gas pressure, cell thickness, field gradient and rf amplitude modulation rate. A theoretical model is developed to understand this line shape. Interesting characteristics of atom- surface interaction, such as dwell time, collision relaxation rate and de-phasing on the surface, can be estimated by fitting the measured line shape with the calculated one.

1This work is supported by the ONR and NSF.

8:48AM N32.00005 Nuclear spin relaxation of 129Xe due to persistent xenon dimers1, B. SAAM, B.N. BERRY-PUSEY, B.C. ANGER, G. LAICHER, Dept. of Physics, University of Utah — An understanding of longitudinal relaxation mechanisms (characterized by the time T1) that limit both achievable polarization and sample storage time is critically important to applications of hyperpolarized noble gases. We have measured T1 for 129Xe in Xe-N2 mixtures at densities < 0.5 amagats in a magnetic field of 8.0 T. The intrinsic relaxation in this regime is due to fluctuations in the intramolecular spin-rotation (SR) and chemical-shift-anisotropy (CSA) interactions, mediated by the formation of 129Xe-Xe persistent dimers. Our results are consistent with previous work done in one case at much lower applied fields where the CSA interaction is negligible and in another case at much higher gas densities where transient Xe dimers mediate the interactions. The 8.0-T field suppresses the persistent-dimer mechanism: we have measured T1 > 25 h at 8.0 T for 129Xe at room temperature. These data also yield a maximum possible low-field T1 for pure xenon gas at room temperature of 3.45 ± 0.2 h.

1Supported by U.S. NSF # PHY-0134980.

9:00AM N32.00006 Geometric Weakening of the Casimir Interaction1, LIVIU MATEESCU, New Jersey Institute of Technology, MARTIN SCHADEN, Rutgers University in Newark — We examine the dependence of the Casimir interaction between separate (metallic) bodies on their geometry. From a semi-classical point of view it depends strongly on whether the dominant periodic orbits are stable or unstable and on the number of focal points. We give a very simple semiclassical argument for the theorem [1] that mirror-symmetric periodically corrugated metallic surfaces always attract. Although counter-intuitive because the Van Der Waals interactions between individual pairs of atoms are attractive at long range, we argue that this need not be the case for multi-atom interactions. Semi-classical methods are used to determine the shape of surfaces with minimal Casimir interaction. [1] O.Kenneth, I. Klich, Phys.Rev.Lett. 97, 160401 (2006).

1This work is supported by the NSF.

9:12AM N32.00007 Casimir force measurements between a sphere and a surface with high-aspect ratio, nanoscale channel arrays. YILIANG BAO, HO BUN CHAN, University of Florida — The Casimir force is a quantum effect that strongly depends on the shape of the boundaries that confines the electromagnetic fields. So far the majority of experiments have concentrated on the simple arrangement of plate-sphere or two parallel plates. Demonstrating the strong shape dependence of the Casimir force would require other geometries with interactions that deviate significantly from the pair-wise summation of two-body potentials. Here we present measurements of the Casimir force between a gold-coated sphere and a silicon plate with an array of nanoscale, high-aspect-ratio rectangular trenches. A micromachined torsional oscillator acts as the force transducer which allows us to measure the interactions between the surfaces at high sensitivity. Channels with widths ranging from 200 nm to 500 nm and depth of 1 μm are fabricated on a silicon substrate. We will compare the Casimir interaction between the sphere and these trench arrays with different aspect ratios. Such measurements might open up new possibilities to manipulate the Casimir force by tailoring the shape of the interacting surfaces.

9:24AM N32.00008 Measurements of the Casimir force in fluids. JEREMY MUNDAY, Department of Physics, Harvard University, Cambridge MA 02138, FEDERICO CAPASSO, Division of Engineering and Applied Sciences, Harvard University, Cambridge MA 02138 — Confinement of the quantum fluctuations of electromagnetic fields between two ground surfaces gives rise to an attractive force first predicted by H. B. G. Casimir. During the past decade, there have been many experimental demonstrations of this force between two metal surfaces in vacuum. While high precision experiments have been performed for this case, few experiments have been done between metallized or dielectric objects in fluids. For this situation, a more general formalism was developed by Lifshitz. If materials are chosen with suitable dielectric response functions, repulsive quantum electrodynamic (QED) forces can also arise. We will discuss experimental results using an atomic force microscope (AFM) to measure the interaction force between a metallized sphere and a plate, made of either metal or dielectric, in fluid.

9:36AM N32.00009 Casimir force measurements between metal and high-\textit{T_c} superconductor surfaces. MARK B. ROMANOWSKY, JEREMY N. MUNDAY, RICHARD SCHALEK, FEDERICO CAPASSO, Harvard University, QIANG LI, GENDA GU, Brookhaven National Laboratory — It is well known that the strength of the Casimir force between two objects is controlled by the dielectric properties (or optical conductivity) of the objects. Nearly all precision measurements of Casimir forces to date are between two metals. Here we report measurements of the Casimir force between a metal-coated sphere and a plate made of the high-$\textit{T_c}$ superconductor BSCCO-2212, using an atomic force microscope at room temperature. BSCCO has dielectric properties substantially different from metals and indeed most materials, displaying extreme anisotropy in dc and optical conductivity, as well as a strange metal” normal state. The force between metal and BSCCO is compared to the force measured between two metals.

9:48AM N32.00010 The Casimir force on transparent conductors. LIMOR SPECTOR, JEREMY MUNDAY, Department of Physics, Harvard University, Cambridge, MA 02138, FEDERICO CAPASSO, NICHOLAS GIESSIE, KEVIN KIT PARKER, Division of Engineering and Applied Sciences, Harvard University, Cambridge, MA 02138 — The Casimir force arises from quantum fluctuations of electromagnetic fields in vacuum and is dependent on the dielectric properties of the interacting materials. This force can have a profound impact on the functionality of systems operating on the micro- and nanoscale. As nanotechnology continues to evolve, the ever-present Casimir force will have to be carefully considered during the design stage. Eliminating or greatly reducing this force could be of tremendous importance. To this end, we have performed Casimir force measurements using atomic force microscopy (AFM) between metals (gold and palladium) and transparent conductors (e.g. indium tin oxide). Due to the transparency of these materials, it is expected that the electromagnetic modes will be less well confined, and the Casimir force will be reduced. Experimental results of such studies will be discussed.
10:12AM N32.00012 Adiabatic change assisted Rabi transitions between Adiabatic change assisted Rabi transitions between decoupled quantum states . XINGXING ZHOU, ARI MIZEL, Pennsylvania State University — A periodic perturbation such as a laser field cannot induce transitions between two decoupled states because the transition matrix element vanishes. However, if in addition some system parameters are varied adiabatically, such transitions are possible via the adiabatic change induced excitations to other states. We study such transitions between two decoupled states and show that full amplitude transfer can be achieved. The resulting physics can be understood in terms of the rotation of an effective spin 1/2 in the two-state subspace, but with a rotation angle dependent on the path traversed by the system in the parameter space only.

10:24AM N32.00013 ABSTRACT WITHDRAWN —

10:36AM N32.00014 Direct Dissociative Recombination of NO$_2$ . DANIEL J. HAXTON, CHRIS H. GREENE, JILA, the University of Colorado and NIST, and Department of Physics, the University of Colorado, Boulder, CO 80309-0440 — We provide estimates for direct dissociative recombination (DR) rates for collisions of NO$_2^+$ and NO$_2$ at energies near the ionization threshold. However, preliminary calculations suggest that the 2 $^2$II and $^2$Φ states may intersect the ground state potential energy curve of the neutral near its Franck-Condon region. R-matrix calculations are employed to obtain the widths of these states, and the direct DR rate is extracted by employing the multidimensional reflection principle along with the formalism of vibronic coupling. A considerable fraction of the low energy Si ions backscattered from monolayers of Cs deposited onto Al(100) are found to be emitted as positive or negative ions. The negative ions result from simple resonant charge transfer (RCT) into the electron affinity level. The formation of Si$^+$, however, is in contrast to the expected complete neutralization due to the overlap with the surface bands. It is proposed that valence electron RCT enhanced by the interaction of the Si ionization level with the Cs 5p level is responsible for the ion formation. Positive ions were also produced in Si scattered from I adatoms on Al(100), presumably by a similar mechanism. The ion fractions are smaller than those for scattering from Cs, which suggests that electron tunneling from the occupied I chemisorption states provides an additional neutralization channel.

Wednesday, March 7, 2007 11:15AM - 2:15PM — Session P32 DAMOP: Bosons in Optical Lattices Colorado Convention Center 402

11:15AM P32.00001 Paired phases of bosons in optical lattices . STEPHEN POWELL, Yale University, SUBIR SACHDEV, Harvard University — We describe the conditions under which bosons in optical lattices can form paired condensates, focusing on the case of bosons with spin. We show that the ground state of such a system, with sufficiently strong spin-dependent interactions, is a spin-singlet condensate, which preserves spin-rotation symmetry. We then consider the gapped single-particle excitations across the phase transition from the insulator, and show that they have nontrivial scaling behavior, determined by coupling to the critical pair modes.

11:27AM P32.00002 Edge States in Cold Atom Optical Lattices1 . VITO SCAROLA, SANKAR DAS SARMA, University of Maryland — We argue that edge state response to external potentials applied to trapped insulators in cold atom optical lattices offer a unique probe of bulk physics. As an example we study the trapped Bose-Hubbard model using Gutzwiller mean-field theory. We calculate the response of Mott insulator edge states to external potentials. We show that the response leads to observables which may be extracted from time of flight measurements.

1This work is supported by ARO-DTO, ARO-LPS, and NSF

11:39AM P32.00003 Superfluid to Mott Transition in the Bose Hubbard Model: Evidence for New Modes . NAOKI KAWASHIMA, YASUYUKI KATO, ISSP, University of Tokyo, Kashiwa, Japan, CHIARA MENOTTI, CRS BEC-INFM and Dipartimento di Fisica, Università di Trento, I-38050 Povo, Italy, NANDINI TRIVEDI, The Ohio State University, Columbus, Ohio — Using a combination of methods (mean-field theory, fluctuations within both phase approximation, and quantum Monte Carlo simulations), we determine the nature of the phases of the Bose Hubbard model. In addition to the sound mode, we find evidence for extra gapped modes in the correlated superfluid phase from the location of the poles of the Green function. We also calculate the effect of thermal and quantum fluctuations on the condensate fraction and compare with recent experiments in optical lattices. In particular, we have obtained the superfluid density and the order parameter independently which agree with each other deep in the condensate phase but disagree in the critical region. We also calculate the Green’s function as a function of the distance and the imaginary time separation, from which we estimate the excitation gap of the boson quasi particles.

11:51AM P32.00004 Lattice with a Twist: A Helical Waveguide for Ultracold Matter1 . M. BHATTACHARYA, University of Arizona — The behavior of matter is governed by the geometry of the potential it experiences. We consider the construction of optical potentials with helical symmetry, which can confine cold atoms and molecules. Microparticles have been experimentally confined in similar potentials [1]. Using two counter-propagating Laguerre-Gaussian beams we show that this simple chiral system realizes a superlattice of helical waveguides for ultracold matter and allows experimental control of their number, helicity, radius, pitch as well as strength and aspect ratio of confinement. In the simplest nontrivial case the potential has double-helical symmetry, similar to DNA. In general the behavior of massive particles in a helical potential is expected to be rich due to the periodic modulation of their motion along the lattice; negative group velocities and effective masses are expected. Effects such as spin squeezing and Berry’s phase are also possible. A helical waveguide can provide a phase hologram for atom-waves, and perhaps support geometrically bound states. We will also address the curious possibility of simulating atom transport in carbon nanotubes.

1Work supported by ARO,NASA,NSF and ONR.


10:48AM N32.00015 Neutralization/Ionization of Si Scattered from Adsorbate Sites . XIAOJIAN CHEN, ZDENEK SROUBEK, JORY YARMOFF, Univ. of California, Riverside — In low energy ion scattering, ion-surface charge exchange strongly depends on the surface electronic structure and the ionization level of the projectile. Si has an ionization level that overlaps the center of the surface conduction band and is intermediate in energy to that of alkali ions and noble gas ions, which are the projectile species traditionally used. The scattering of Si thus provides new pathways for ion-surface charge exchange. A considerable fraction of the low energy Si$^+$ ions backscattered from monolayers of Cs deposited onto Al(100) are found to be emitted as positive or negative ions. The negative ions result from simple resonant charge transfer (RCT) into the electron affinity level. The formation of Si$^+$, however, is in contrast to the expected complete neutralization due to the overlap with the surface bands. It is proposed that valence electron RCT enhanced by the interaction of the Si ionization level with the Cs 5p level is responsible for the ion formation. Positive ions were also produced in Si scattered from I adatoms on Al(100), presumably by a similar mechanism. The ion fractions are smaller than those for scattering from Cs, which suggests that electron tunneling from the occupied I chemisorption states provides an additional neutralization channel.
12:03PM P32.00005 Tunneling resonances and entanglement dynamics of ultracold bosons in a tilted two-well potential\textsuperscript{1}. DIMITRI DOUNAS-FRAZER, ANN HERMUNDSTAD, LINCOLN CARR, Physics Department, Colorado School of Mines, Golden, CO, 80401 — We study the quantum sloshing of ultracold bosons in a tilted double-well potential via exact diagonalization of the two-mode Bose-Hubbard Hamiltonian. Tunneling is extremely sensitive to a small potential difference between wells, or tilt. However, when the barrier is high,atom interactions can compensate the tilt and produce a tunneling resonance \cite{1, 2}. At resonance, tunneling times on the order of 10-100 ms are possible. Furthermore, tunneling resonances constitute a dynamic scheme for creating robust few-atom entangled states in the presence of many bosons. 
\textsuperscript{1}We gratefully acknowledge support from the NSF.
\textsuperscript{2}This work is supported in part by ARO, NASA, NSF, and ONR.

12:15PM P32.00006 Gravity QED determination of atomic number statistics in optical lattices\textsuperscript{2}. WENZOU CHEN, DOMINIC MEISER, PIERRE MEYSTRE, University of Arizona — We study the reflection of two counter-propagating modes of the light field in a ring resonator by ultracold atoms either in the Mott insulator state or in the superfluid state of an optical lattice. We obtain exact numerical results for a simple two-well model and carry out statistical calculations appropriate for the full lattice case. We find that the dynamics of the reflected light strongly depends on both the lattice spacing and the state of the matter-wave field. Depending on the lattice spacing, the light field is sensitive to various density-density correlation functions of the atoms. The light field and the atoms become strongly entangled if the latter are in a superfluid state, in which case the photon statistics typically exhibit complicated multimodal structures.

12:27PM P32.00007 Bose-Einstein Condensates in Optical Lattices: Resonantly Enhanced Tunneling and Nonlinear Effects. ALESSANDRO ZENESINI, CARLO SIAS, LIGNIER HANS, YESHPAL SINGH, DONATELLA CIAMPINI, SANDRO WIMBERGER, RICCARDO MANNELLA, OLIVER MORSCHE, ARIMONDO ENNIO, University of Pisa — In our experiments we study the tunneling between different sites of a periodic potential in the presence of an external force. As a consequence of Wannier-Stark localization of atomic wavefunctions inside the single lattice sites, Resonantly Enhanced Tunneling (RET) occurs when the spacing between energy levels in a potential well is equal to the field-induced energy shift between different wells. These resonances are an important modification to the smooth Landau-Zener formula. We observed RET using Bose-Einstein condensates in accelerated optical lattice potentials. We have perfect control over the parameters of this system: the depth of the lattice $U_0$, the recoil energy $E_{rec}$, and the peak density $n_0$ in the dipole trap. The latter determines the nonlinear interaction energy of the system, which allowed us to study the behavior of condensates in different regimes of the nonlinearity. In the linear case, as predicted in the Wannier-Stark solution, we observed RET and we verified the dependence between the positions of the resonances and the lattice depth for tunneling between 1$\text{st}$, 2$\text{nd}$ and 3$\text{rd}$ neighboring sites. In the nonlinear regime, we observed a suppression of the resonances for increasing nonlinearity, in agreement with numerical simulations.

12:39PM P32.00008 Phase diagram for ultracold bosons in double-well optical lattices\textsuperscript{1}. IPPEI DANSHITA, JAMES E. WILLIAMS, NIST, Gaithersburg, MD 20899, CARLOS SA DE MELO, School of Physics, Georgia Institute of Technology, Atlanta, GA 30332, CHARLES W. CLARK, NIST, Gaithersburg, MD 20899 — We study the superfluid-Mott insulator transition of bosons in double-well optical lattices. Applying a mean-field approximation to the Bose-Hubbard Hamiltonian, we obtain the zero-temperature phase diagram and find that there exist the half-integer-filling and integer-filling Mott insulator domains in the phase diagram. We show that the half-integer-filling Mott insulator phase is stabilized as the intra-well hopping energy increases. We also calculate the phase diagram by employing the time evolving block decimation (TEBD) algorithm and compare the results obtained from the mean-field approximation with those from the TEBD.

12:51PM P32.00009 On-site number statistics of ultracold lattice bosons. EVGENY KOZIK, BARBARA CAPOGROSSO-SANSONE, NIKOLAY PROKOF'EV, BORIS SVISTUNOV, University of Massachusetts Amherst — We study on-site occupation number fluctuations in a system of interacting bosons in an optical lattice. The ground-state distribution is obtained analytically in the limiting cases of strong and weak interaction, and by means of exact Monte Carlo simulations in the strongly correlated regime. As the interaction is increased, the distribution evolves from Poissonian in the non-interacting gas to a sharply peaked distribution in the Mott-insulator (MI) regime. In the special case of large occupation numbers, we demonstrate analytically and check numerically that there exists a wide interval of interaction strength, in which the on-site number fluctuations remain Gaussian and are gradually squeezed until they are of order unity near the superfluid (SF)-MI transition. Recently, the on-site number statistics were studied experimentally in a wide range of lattice potential depths [Phys. Rev. Lett. 96, 090401 (2006)]. In our simulations, we are able to directly reproduce experimental conditions using temperature as the only free parameter. Pronounced temperature dependence suggests that measurements of on-site atom number fluctuations can be employed as a reliable method of thermometry in both SF and MI regimes.

1:03PM P32.00010 Phases in an anisotropic two-dimensional optical lattice. SARA BERGKVIST, ANDERS ROSENGREN, KTH, ROBERT SAERS, EMIL LUNDH, MAGNUS REHN, ANDERS KASTBERG, Umeå University — We have studied the effects of anisotropy on a two-dimensional optical lattice potential using Monte Carlo simulations. For finite lengths, such a system undergoes a one-dimensional quantum phase transition to a 1D Mott insulator of decoupled chains. Time of flight pictures and other measurable observables are calculated for a specified experimental setup.

1:15PM P32.00011 Mach-Zehnder Interference of Boson Flavor States in the Excited Band of a 2D Optical Lattice\textsuperscript{1}. JOHN CHALLIS, STEVEN GIRVIN, Yale University, LEONID LEVITOV, MIT — Bosons promoted to the first excited Bloch band of an optical lattice have two important properties: they are metastable, having lifetimes long compared to the nearest neighbor hopping rate, and they carry a “flavor” quantum number which controls the direction of highly anisotropic hopping in the lattice. For a 2D optical lattice where the laser beams are not quite perpendicular, there is a small energy which causes the flavors to mix. The two flavor states can be treated as a two-level system with an avoided crossing, with the relative intensity of the two laser beams serving as a tuning parameter controlling the energy difference between the two flavors. When the tuning parameter is varied sinusoidally around some nonzero offset, the avoided crossing acts like a beam splitter in a Mach-Zehnder interferometer. Since this offset is momentum dependent, the rate of flavor change varies throughout the Brillouin Zone. This fact leads to interesting time-dependent momentum distributions which should be readily observable experimentally by free expansion of the bosons.

\textsuperscript{1}NSF DMR-0603369 and NSF Graduate Fellowship
The correspondence principle with spinor condensates: from quantum Bloch oscillations to classical Bogoliubov excitations\(^1\). REINHOLD WALSER, University of Ulm, Abteilung Quantenphysik, D-89081, Germany, CARSTEN WEIB, OLIVER CRÄSSER, WOLFGANG SCHLEICH — By tuning the relative strength between single and two-body energies in a spinorial F=1 Bose-Einstein condensate (e.g. \(^{87}\)Rb), we can effectively control the dynamics of the macroscopic Fock-state \([1,2,3]\). We will study the static as well as dynamic aspects of this few mode quantum system and illustrate the “classical” as well as quantum aspects of this system, which can be realized in deep optical lattices.


Dispersive shock waves in optical lattices\(^1\), SHU JIA, WENJIE WAN, JASON FLEISCHER. Princeton University — We study dispersive, superfluid-like shock waves in optical lattices. Compared with the homogeneous case, the presence of a periodic potential inhibits shock propagation, both via Peierls-Nabarro trapping forces and through Bragg reflections. Photonic experiments are performed in SBN photorefractive crystals, using optical induction to create nonlinear waveguide arrays. By applying defocusing (repulsive) nonlinearity, we directly observe the nonlinear properties of shock waves as a function of the intensity of lattice, i.e. the depth of the potential wells. Direct comparisons are made between a plane-wave background, suitable for homogeneous systems, and Bloch-wave backgrounds, which are more appropriate for arrays. Nonlinear coupling between transmission bands is demonstrated, with numerical simulations showing excellent agreement with experimental results. Similarities between photonic systems and cold atom systems in periodic potentials will be discussed.

Evolution of Hard-Core Bosons in a Time-Dependent Trap, ADITYA RAGHAVAN, MARCOS RIGOL, STEPHAN HAAS, Department of Physics and Astronomy, University of Southern California — We present a study of the time evolution of hard-core bosons (HCB) in a one-dimensional, time-varying optical trap. Previous results have shown that one-dimensional HCBs can form superfluid and Mott-insulator phases. Using numerical techniques in the Bose-Hubbard model, we explore different types of time variations, such as sinusoidally varying trap curvature, using either initial configurations (filling & trap curvature) of a superfluid or a Mott-insulator. When the curvature of the optical trap is suddenly increased, we observe a “melting” of the Mott-insulator. The approximate numerical technique used to study time-varying traps is discussed.

Quantum phases and phase transitions in bosonic mixtures induced by non-s-wave Feshbach resonances in optical lattices\(^2\), ANATOLY KUKLOV, CSI, CUNY — Feshbach resonance at finite angular momentum in a mixture of distinguishable bosons in optical lattice (OL) can induce quantum phase transitions (QPTs) into states which break OL symmetries and time reversal. In particular, a two-component mixture, with one component being superfluid and the other Mott insulator, can undergo QPT into, e.g., p-wave condensate characterized by lines of zeros, spontaneous currents and by strong quantum depletion. The ground state is sensitive to rotation of OL. Analogously, a featureless two-component Mott insulator can undergo QPT into the insulator with broken lattice symmetries. While impossible for an absolute ground state, such effect can be realized in the context of metastable phases generic for atomic traps and OLs as long as there is a large energy difference between the resonance and true molecular ground state. A condition for such transition is that the closed-open channels coupling exceeds the onsite excitation energy in the regime of weak tunneling between sites. Standard imaging techniques can be used to identify such phases.

1 Author acknowledges support by NSF PHY-0426814 grant and hospitality of the Aspen Center for Physics.
2 A.B.Kuklov, PRL 97, 110405(2006)

Wednesday, March 7, 2007 2:30PM - 5:30PM –
Session S4 DAMOP: Disordered Quantum Gases Colorado Convention Center Korbel 2B-3B

Ultracold Atoms in Optical Potentials and Novel Quantum Phases, MASSIMO INGUSCIO, LENS, University of Florence — The experimental study of ultracold atoms in optical lattices has thrown a bridge between the realms of atomic physics and solid state physics. Laser beams in standing wave configuration provide ideal periodic potentials for the atoms, thus constituting a test ground for the quantum theory of transport in periodic structures. On the other hand, laser light can also be used to engineer controlled disorder in the form of speckle fields or multi-chromatic lattices with incommensurate wavelengths. These aperiodic potentials can be used to study the physics of disordered systems and the emergence of quantum localization phases, such as Anderson insulators or strongly interacting Bose Glass phases. I will review some of the latest advances in this exciting field, discussing experiments with quantum degenerate gases in disordered optical potentials.

Localisation of interacting Bose-Einstein Condensates expanding in a 1D random potential created by laser speckle, LAURENT SANCHEZ-PALENCIA\(^1\), Laboratoire Charles Fabry de l’Institut d’Optique — We have studied the 1D expansion of a coherent interacting matter wave (a Bose-Einstein condensate) in the presence of disorder. Well controlled 1D random potentials are produced with laser speckle patterns. We observe the suppression of the transport of the BEC in the random potential, and we study this localisation phenomenon as a function of the parameters of the random potential. A theoretical analysis and numerical simulations allow us to interpret the observed behaviours.

1 CNRS et Université Paris Sud 11
3:42PM S4.00003 Mott-insulator phases of coupled two-component Bose gases\(^1\). LUIS SANTOS, Institut fuer Theoretische Physik, Universitaet Hannover, Appelstr.2, 30167, Hannover (GERMANY) — In recent years, strongly-correlated atomic gases have attracted a rapidly-growing attention, mostly motivated by the impressive developments in the manipulation of atoms in optical lattices. In particular, if cold bosons in lattices occupy just the lowest band of the corresponding band structure, the physics is then described by the Bose-Hubbard model, which presents two different types of ground states, namely a superfluid phase and a gaped incompressible insulator phase known as Mott-insulator, characterized by a commensurate occupation pattern of bosons sites. Here we report on effusive beams of an ultra-cold mixture of bosons in a trap, and in particular a pair superfluid phase, i.e. a superfluid of boson-boson (or hole-hole) composites [1]. In this work we analyze how the formation of a pair-superfluid may significantly influence the qualitative shape of the boundaries of the Mott-insulator regions. We discuss first that our results are relevant for both binary Boson-Boson mixtures, as well as for the case of dipolar gases placed in two disconnected neighboring one-dimensional wires. By combining strong-coupling-expansion calculations, and one-dimensional numerical results based on Matric-Product-state techniques, we show that the Mott-boundsaries strongly modify their shape, acquiring a marked re-entrant character even for low tunneling, which persists even for two-dimensional systems. Finally, we comment on the consequences that this effect may have in the spatial extension of the Mott Insulator plateau in experiments with an inhomogeneous harmonic trapping in addition to the lattice potential. [1] A. kuklov, N. Prokof’ev, and B. Svistunov, Phys. Rev. Lett. 92, 050402 (2004).

\(^1\)This work was supported by the DFG (SFB-TR21, SFB407, SPP1116).

4:18PM S4.00004 Prospects for strong localization of matter waves by scattering from atoms in a lattice . YVAN CASTIN, Laboratoire Kastler Brossel, Ecole normale supérieure (Paris) — Non-interacting matter waves in a disordered potential may exhibit localized states, that is eigenstates with an energy above the potential and with a square integrable wave-function. This intriguing quantum property, related to the concept of Anderson or strong localization, is not straightforward to observe experimentally as in many systems the situation is made complex by interaction and decoherence effects. Ultracold atoms are very flexible systems, where the parasitic effects may be reduced; they are good candidates to observe strong localization if one is able to produce a strong enough disorder. It has been proposed to realize a controllable disorder for matter waves by randomly trapping atoms of another species at the nodes of an optical lattice, with a filling factor less than unity. For the matter wave the optical lattice is far detuned and is assumed to have a negligible mechanical effect. The matter wave then only sees the trapped species, which, in a regime of negligible tunneling, constitutes a static disordered potential of point-like scatterers [1]. We analyze the possibility to observe three-dimensional strong localization of matter waves with this realization of disorder [2]. We show that, provided one is able to adjust the effective scattering length of a trapped scatterer to a value close to the mean inter-scatterer separation d, one can produce localized states with a localization length as short as d, in practice in the micrometer range. We have obtained the value of the effective scattering length by solving the two-body problem of scattering of a free matter wave on a harmonically trapped atom. We predict confinement induced resonances, with an identified physical origin, that may be used to tune the effective scattering length to the desired value, in combination with an interspecies Feshbach resonance.


4:54PM S4.00005 Weak and strong localization of cold bosons in optical speckle potentials . CORD A. MÜLLER, Universität Bayreuth, Germany — Cold bosons in optical speckle potentials allow to study quantum transport in various geometries under the influence of disorder and interactions. We use an effective-interrupt function approach to calculate the quantum diffusion constant for cold bosonic matter waves in the single-particle regime in optical speckle potentials. These random potentials display strong correlations that were suspected to reduce quantum coherent effects. Our analytical linearity-response theory shows that current experiments should be able to measure weak localization corrections to the classical Boltzmann diffusion constant, even in 2 or 3 dimensions. Moreover, the threshold to the strongly (or Anderson) localized regime is accessible if atoms are cold enough and prepared with a sufficiently small momentum dispersion [R. Kuhn et al., Phys. Rev. Lett. 95, 250403 (2005)].

Wednesday, March 7, 2007 2:30PM - 5:30PM
Session S32 DAMOP: Slow Molecular Beams and Quantum Optics Colorado Convention Center 402

2:30PM S32.00001 Slow beams of molecules with masses up to 6000 u . HENDRIK ULRICH, SARAYUT DEACHAPUNYA, ANDRE STEFANOV, MARKUS ARNDT, Faculty of Physics, University of Vienna, Boltzmanngasse 5, 1090 Vienna, Austria — Slow molecules are desirable for various experiments, among them matter wave interferometry, precision metrology, collision studies and the improved control in the deposition of molecular nanopatterns. Here we report on effusive beams of intact per-fluorinated molecules with masses up to 6000 u and beyond. The molecules in these beams are observed to have a mean velocity of down to 30 m/s. And the mass selected signals of the post-ionized particles are so high that even molecules with a longitudinal velocity as low as 10 m/s and with a transverse velocity below 10 cm/s can still be detected. We discuss potential strategies and applications for further slowing, trapping and focusing of these molecules.

2:42PM S32.00002 Magnetic trapping of Stark decelerated OH . BENJAMIN LEV, BRIAN SAWYER, ERIC HUDSON, BENJAMIN STUHL, MANUEL LARA, JOSH DUNN, CHRIS GREENE, JOHN BOHN, JUN YE, JILA/NIST. of Colorado — Ultracold, ground state polar molecules promise to revolutionarily impact AMO physics with the study of ultracold molecular collisions and quantum chemistry, implementation of quantum information processing, and the possibility of lattice-spin model simulations. Our research has focused on the use of a Stark decelerator to slow a supersonic expansion of OH. At a mean packet velocity of 20 m/s, we obtain a ~10 mK sample at densities greater than \(10^7\) cm\(^{-3}\). The decelerator terminates at an anti-Helmholtz coil pair which we have used to demonstrate magnetic trapping of the polar molecule OH in the presence of tunable electric fields. We will present our latest results on trapping dynamics as well as discuss the feasibility of molecular cavity-assisted laser cooling, which may provide access to the ultracold regime.

2:54PM S32.00003 A four-wave-mixing source of low-frequency squeezed light , COLIN MCCORMICK, VINCENT BOYER, Natl Inst of Standards and Tech, ENNIO ARIMONDO, Universita’ di Pisa, Pisa, Italy, PAUL LETT, Natl Inst of Standards and Tech — Squeezed-light sources whose spectrum of squeezing extends down to acoustic frequencies are potentially useful in a variety of applications, from gravitational-wave detection to photo-thermal interferometry. To date, the only light sources able to generate squeezing at these low frequencies are based on parametric down-conversion in optical cavities, and require a substantial number of feedback loops to stabilize them. We have developed an alternative low-frequency squeezed-light source, using four-wave mixing in a hot gas of rubidium atoms. Our system generates macroscopic twin beams near the D1 line of rubidium that display \(\Delta \Omega \geq 6\) dB of relative-intensity squeezing as low as \(70\) kHz. This technique for generating low-frequency squeezed light is particularly robust, since it involves no optical cavity and only a simple vapor cell. The only feedback electronics present are the standard commercial laser-stabilization electronics of our pump. The low-frequency limit of our squeezing spectrum is set by the pump laser’s intensity stability, and we anticipate that the addition of a simple noise eater should allow us to push the squeezing spectrum fully into the acoustic band.
interaction length between light and ions can be made very long within a waveguide. Thus high optical depth can be achieved as required for the proposal.

SIMON, University of Geneva, W. TITTEL, University of Calgary, N. GISIN, University of Geneva — Erbium doped waveguides are very promising candidates, M.U. STAUDT, S.R. HASTINGS-SIMON, B. LAURITZEN, M. AFZELIUS, H. DE RIEDMATTEN, N. SANGOUARD, C.

A Quantum Memory unit cell of the array can be designed to be of deep sub-wavelength scale, miniaturizing the circuit.

be stopped, stored, and time-reversed. With a properly designed array, two photons can be stopped and stored in the system at the same time. Moreover, the systems. Furthermore, by cascading double-qubit structures to form an array and dynamically controlling the qubit transition frequencies, a single photon can be stopped, stored, and time-reversed. With a properly designed array, two photons can be stopped and stored in the system at the same time. Moreover, the unit cell of the array can be designed to be of deep sub-wavelength scale, miniaturizing the circuit.

3:42PM S32.00007 Coherence Investigations of Erbium doped in Waveguide Structures for a Quantum Memory , M.U. STAUDT, S.R. HASTINGS-SIMON, B. LAURITZEN, M. AFZELIUS, H. DE RIEDMATTEN, N. SANGOUARD, C. SIMON, University of Geneva, W. TITTEL, University of Calgary, N. GISIN, University of Geneva — Erbium doped waveguides are very promising candidates for the realization of a quantum memory based on reversible absorption in a controllably broadened absorption line (CRIB). First of all, the wavelength of the “storage transition” matches well with the telecommunication wavelength most often used for long-distance quantum communications in the past. Secondly, the interaction length between light and ions can be made very long within a waveguide. Thus high optical depth can be achieved as required for the proposal. We have measured the homogeneous linewidth of the $\chi_{1/2} \rightarrow \chi_{3/2}$ transition in a Erbium-doped SiO$_2$ glass fiber and a LiNbO$_3$ Crystal with a waveguiding structure at a wavelength of $\lambda=1530$ nm. The homogeneous lifetime in the glass shows an abnormal magnetic field dependency and is in the order of several $\mu$s, which is an improvement of two orders of magnitude compared to existing data in similar material. Also we investigated the preservation of information encoded into the relative phase and amplitudes of optical pulses during storage and retrieval in an optical memory based on stimulated photon echo.

3:54PM S32.00008 Dispersive, superfluid-like shock waves in optics , WENJIE WAN, SHU JIA, JASON FLEISCHER, Princeton University — Dispersive shock wave arises from nonlinear wave breaking and mode dispersion, and are a fundamental type of fluid behavior in systems with non or near-zero viscosity, e.g. cold plasmas and superfluids. Here, we exploit the well-known (but underappreciated) relation between superfluids and nonlinear optics to study the photonic equivalent of dispersive, dissipationless shock waves. We experimentally demonstrate fundamental shock waves in one and two dimensions, examine their basic nonlinear properties, and observe collisions between two such shocks. We study spectral energy exchange during interactions, and find that energy and momentum transfer depend on details of the collision region. Results can be explained in terms of a nonlinear Huygens' principle, in which linear superposition of initial waves results in a nonlinear source of new shocks. In higher dimensions, wavefront geometry and expansion directions play a significant role. In addition to providing a versatile platform for new photonic physics, it is anticipated that the results reported here will lead to all-optical modeling of even richer (super)fluid-like phenomena in the near future.

4:06PM S32.00009 Coherent Quantum Engineering of Laser Cooling , JOSH W. DUNN, CHRIS H. GREENE, JILA, University of Colorado and NIST, and Department of Physics, University of Colorado, Boulder, Colorado, J. W. THOMSEN, The Niels Bohr Institute, Copenhagen, DENMARK, FLAVIO C. CRUZ, Instituto de Física Gleb Wataghin, Universidade Estadual de Campinas, Campinas, Brazil — Doppler laser cooling of two-level atoms is well understood, and has been utilized extensively for decreasing phase-space density of atomic gases. The temperature limit of Doppler cooling is on the order of the excited-state spectral linewidth, and cooling below this limit requires, for example, atomic sublevel degeneracy. Here we present a means of cooling that consists of three internal states of an atom and two lasers of distinct frequency. Employing sparse-matrix techniques, we find numerical solutions to the fully quantized master equation in steady state, allowing straightforward determination of laser-cooling temperatures. We develop a qualitative picture of the mechanism, related to the phenomenon of electromagnetically induced transparency, yielding a cooling scheme in which a dressing laser can be tuned to coherently engineer a two-level quantum system that has desirable Doppler-cooling properties. Effects of the induced asymmetric Fano-type lineshapes affect the detunings required for optimum cooling, as well as the predicted minimum temperatures which can be lower than the Doppler limit for either transition. This work was supported in part by the NSF.

4:18PM S32.00010 Three Level Systems for Quantum Memories in Erbium Doped Materials , SARA HASTINGS-SIMON, MATTHIAS STAUDT, BJÖRN LAURITZEN, MIKAEL AFZELIUS, HUGUES DE RIEDMATTEN, NICOLAS SANGOUARD, CHRISTOPH SIMON, University of Geneva, WOLFGANG TITTEL1, NICOLAS GISIN, University of Geneva — Quantum memories for single photons could play an important role in quantum communication and computing applications. We are working towards the realization of such a quantum memory based on the controlled reversible inhomogeneous broadening (CRIB) of a single absorption line in a rare earth ion. The implementation of the CRIB protocol for such a quantum memory requires a three level system such that the absorption over a broad bandwidth in a material can be greatly reduced via optical pumping to the auxiliary level. We report on the first step experimental steps towards the realization of such a three level systems in Erbium doped materials with optical pumping and burning techniques.

1University of Calgary
4:30PM S32.00011 A Kapitza-Dirac Talbot-Lau interferometer for molecules, STEFAN GERLICH, LUCIA HACKERMUELLER, FABIENNE GOLDFARB, KLAUS HORNBERGER, TIM SAVAS, ALEXANDER STIBOR, HENDRIK ULERICH, MARKUS ARNDT, University of Vienna — We present a novel matter-wave interferometer setup which is designed for particles with wavelengths down to 0.5 pm. Such a short wavelength corresponds for instance to a mass of 7000 atomic mass units (amu) at a velocity of 100m/s. Such an advance in mass and complexity can only be accomplished by introducing a standing light wave [1,2,3] to replace the central material grating used in a standard Talbot-Lau interferometer [4]. Light gratings combine high transmission with the absence of the perturbing van der Waals forces otherwise encountered at material gratings. This is particularly desirable for the investigation of the wave-particle duality of large molecules with high polarizabilities. We show the first successful application of this interferometer with C70-Fullerenes. Preliminary studies with sources and detection schemes for molecules of up to 7000 amu are very promising for interference experiments with such large and heavy objects in the immediate future. [1] P. Gould et al., Phys. Rev. Lett. 56, 827 (1986) [2] D. Freimund et al., Nature 413, 142 (2001) [3] O. Nairz et al., Phys. Rev. Lett. 87, 160401 (2001) [4] B. Brezger et al., J. Opt. B 5, 82 (2003)

1NanoStructures Laboratory, MIT

4:42PM S32.00012 Quantum phase transitions for light and XY spin models in coupled cavity arrays, DIMITRIS ANGELAKIS, Centre for Quantum Computation, University of Cambridge, MARCELO FRANCA SANTOS, Universidade Federal de Minas Gerais, Brazil, SOUGATO BOSE, Department of Physics, University College London — The realization of insulator to superfluid transitions in optical lattices have opened great possibilities for simulating many body systems. It is thus interesting to explore which other systems permit such phases and simulations, especially if the problem of accessibility of the individual sites is not present. Particularly arresting will be to find such phases in a system of photons which, by being non-interacting, are unlikely candidates for the studies of many-body phenomena. Here we show that a Mott phase can arise in an array of coupled high Q electromagnetic cavities between which photons can hop, when each cavity is coupled to a single two level system (atom/quantum dot/superconducting qubit). In this phase each atom-cavity system has the same integral number of net (atomic plus photonic) excitations. It occurs for resonant photonic and atomic frequencies when the photon blockade effect provides an effective repulsion between the excitations in each atom-cavity system. Detuning the atomic and photonic frequencies suppresses this repulsion and induces a transition from the Mott phase to a photonic superfluid. We show that for zero detuning, the system can simulate the dynamics of an XY spin chain with arbitrary number of excitations.

4:54PM S32.00013 Moments Formulation of Optical-Pulse Propagation in Insulators1, DAVID Y. SMITH, University of Vermont and Argonne National Laboratory, WILLIAM KARSTEN, Saint Michael’s College — We have developed general expressions for the group velocity and its dispersion in insulators in terms of moments of the material’s IR (ionic) and UV (electronic) absorptions. The formulation, which is based on Kramers-Kronig dispersion theory, is independent of material models, and involves only independently measurable quantities. The carrier frequency at which a signal propagates with minimum distortion is determined by the ratio of the first moment of the ionic absorption to the inverse-third moment of the electronic absorption. This represents a balance between ionic and electronic effects and depends only on their respective contributions to dispersion in the index, not on the magnitude of the refractive index. Physically, minimum distortion corresponds to propagation of a compound ionic-electronic polaron at a frequency for which the ionic and electronic components remain in phase. Applications to silicate-glass fibers will be considered. This is a generalization of a result given by S. H. Wemple, Appl. Opt. 18, 31 (1979).

1Work supported by US Department of Energy, Office of Science, Materials Science Division under contract DE-FG02-02ER45064, and Office of Nuclear Physics under contract DE-AC02-06CH11357.

5:06PM S32.00014 Controlled Spontaneous Emission, M.A. ROHRDANZ, Walsh University, N. Canton, OH 44720, USA, J.-S. LEE, A. KHITRIN, Department of Chemistry, Kent State University, Kent, OH 44242, USA — The problem of spontaneous emission has been studied by numerical simulations. The dynamics of the combined system atom + radiation field, involving up to 15 k field oscillators, has been calculated by direct diagonalization of the Hamiltonian. Optimization of the discrete model’s parameters was made by comparing results with the exact solution for the model with equidistant frequencies of the oscillators and equal coupling constants. A numerical approach made it possible to address problems too complex for analytical treatment, which involve interaction with external fields and emission by multi-atom systems. Our major findings are the following. 1) Irradiation by a periodic sequence of laser pulses may shift the frequency in a continuous way by attenuating the power of the pulses. 2) In a two-atom system, the linewidth of the emitted spectrum can be made arbitrary small, and can be regulated by changing a difference between the transition frequencies of the atoms. Therefore, both the frequency and linewidth of spontaneous emission can be controlled.

5:18PM S32.00015 ABSTRACT WITHDRAWN —

Thursday, March 8, 2007 8:00AM - 10:48AM Session U32 DAMOP: Focus Session: Novel Phases in Quantum Gases Colorado Convention Center 402

8:00AM U32.00001 Cold Atoms on Frustrating Lattices, DAGIM TILAHUN, ALLAN MACDONALD, The University of Texas at Austin — Ultracold atoms in optical lattices undergo a quantum phase transition from a superfluid to a Mott insulator as the lattice potential depth is increased. We present a theory of the ground state and the elementary excitations of cold atoms in which the potential $\Sigma$ which induces coherence between different number states on a given site is elevated from a variational parameter to a quantum degree of freedom. In this approach mean-field theory is equivalent to minimizing the energy with respect to the $\Sigma$. The theory is applied to the Boson Hubbard model of optical lattice systems, to frustrated lattice models for rotating atoms, and to inhomogeneous systems with a harmonic trapping potential superimposed on the lattice potential.

8:12AM U32.00002 Atomtronics: Ultracold atom analogs of electronic circuits and devices, RONALD FEPINO, BRIAN SEAMAN, MURRAY HOLLAND, JILA, NIST, CU Boulder — Atomtronics focuses on creating an analogy between electronic devices and circuits with ultracold atoms. Such an analogy can come from the Mott-insulator characteristic of ultracold gases trapped in optical lattices. The highly tunable parameters of optical lattices allow one to construct and precisely manipulate them. This lets one to create conditions that cause atoms in lattices to exhibit the same behavior as electrons moving through solid state media. We present our model and show how the atomtronic diode and the field effect transistor can be realized. These fundamental components can lead to the construction of other atomtronic devices such as the bipolar junction transistor and possibly amplifiers and switches. Besides the similarities to condensed matter systems, there are also differences that can be explored: atomtronic current carriers can be either bosons or fermions having spin not equal to 1/2. Also, there are no thermal fluctuations or phonon modes associated with the lattice itself.
8:24AM U32.00003 Reversible quantum phase dispersion in two-component quantum gases, A. WIDERA, S. TROTZKY, P. CHEINET, S. FÖLLING, F. GEBRER, I. BLOCH, Physics Department, University of Mainz, 55099 Mainz, Germany — Controlling fundamental interactions on an atomic scale has offered the unique possibility to engineer strongly correlated quantum states in ultracold atomic samples during recent years. In particular, controlling the interactions of an ensemble of particles implies the possibility of pushing into the intriguing regime of coherent many-body physics. Here we report on the controlled manipulation of a quantum many-body state in a 2D-array of mesoscopic spinor gases. Starting from a coherent spin-state, controllable interatomic interactions close to a Feshbach resonance are used to induce a dynamics which changes the distribution of intrinsic spin fluctuations. The resulting phase dispersion is detected by monitoring the decay of coherence through Ramsey spectroscopy. We demonstrate the coherent nature of this interaction effect by time-reversal of the dynamics, observing a substantial revival of coherence in the system. These results have implications not only on our understanding of decoherence in ultracold atomic systems but also point towards the possibility of dynamically creating correlated spin states or even maximally entangled mesoscopic Schrödinger cats.

8:36AM U32.00004 Finite quantal systems – from semiconductor quantum dots to cold atoms in traps1, STEPHANIE M. REIMANN, Lund Institute of Technology, Lund University — Many-body systems that are set rotating may form vortices, characterized by rotating motion around a central cavity. This is familiar to us from every-day life: you can observe vortices while stirring your coffee, or watching a hurricane. In quantum physics, vortices are known to occur in superconducting films and rotating bosonic He-4 or fermionic He-3 liquids, and recently became a hot topic in the research on cold atoms in traps. Here we show that the rotation of trapped particles with a repulsive interaction may lead to vortex formation regardless of whether the particles are bosons or fermions. The exact many-particle wave function provides evidence that the mechanism is very similar in both cases. We discuss the close relation between rotating BECs and quantum dots at strong magnetic fields. The vortices can stick to particles to form composite particles, but also occur without association to any particular particle. In quantum dots we find off-electron vortices that are localized, giving rise to charge deficiency or holes in the density, with rotating currents around them. The vortex formation is observable in the energetics of the system. “Giant vortices” may form in anharmonic potentials. Here, the vortices accumulate at the trap center, leading to large cores in the electron and current densities. Turning from single traps to periodic lattices, we comment upon the analogies between optical lattices with cold fermionic atoms, and regular arrays of few-electron quantum dots. Trapping a few (N < 12) fermions in each of the single minima of the lattice, we find that the shell structure in the quantum wells determines the magnetism, leading to a sequence of non-magnetic, ferromagnetic and antiferromagnetic states.

1Work supported by the Swedish Research Council and the Swedish Foundation for Strategic Research.

9:12AM U32.00005 Thermal Fluctuations of Vortex Matter in Trapped Bose-Einstein Condensates, STEINAR KRAGSET, Norwegian University of Science and Technology, EGOR BABADEV, Royal Institute of Technology, Sweden, ASLE SUDBO1, Norwegian University of Science and Technology — We perform Monte Carlo studies of vortices in three dimensions in a cylindrical confinement, with uniform and nonuniform density. The former is relevant to rotating 4He, the latter is relevant to a rotating trapped Bose–Einstein condensate. In the former case we find dominant angular thermal vortex fluctuations close to the cylinder wall. For the latter case, a novel effect is that at low temperatures the vortex solid close to the center of the trap crosses directly over to a tension-less vortex tangle near the edge of the trap. At higher temperatures an intermediate tensionful vortex liquid located between the vortex solid and the vortex tangle, may exist.

1Work supported by NSF and Research Council of Norway.

9:24AM U32.00006 Radial and angular rotons in trapped dipolar gases1, SHAI RONEN, JILA and Department of Physics, University of Colorado, Boulder, CO 80309-0440, USA, DANIELE BORTOLOTTI, JILA and Department of Physics, University of Colorado, Boulder, CO, USA; LENS and Dipartimento di Fisica, Università di Firenze, Italy, JOHN BOHN, JILA, NIST, and Department of Physics, University of Colorado, Boulder, CO 80309-0440, USA — We study Bose-Einstein condensates with purely dipolar interactions in oblate (pancake) traps. We find that the condensate always becomes unstable to collapse when the number of particles is sufficiently large. We analyze the instability, and find that it is the trapped-gas analogue of the “roton-maxon” instability previously reported for a gas that is unconfined in two dimensions. In addition, we find that under certain circumstances, the condensate wave function attains a biconcave shape (like a red-blood cell), with its maximum density away from the center of the gas. These biconcave condensates become unstable due to azimuthal excitation – an angular roton.

1USIEF (Fulbright program); DOE and the Keck Foundation.

9:36AM U32.00007 Cold atoms in time dependent optical lattices, I. B. SPIELMAN, B. BROWN, P. LEE, N. LUNDBLAD, J. V. PORTO, W. D. PHILLIPS, National Institute of Standards and Technology — Cold atoms in optical lattices provide new avenues for studying iconic condensed matter problems. Using an initially Bose condensed sample of 87Rb atoms, we first implement the Bose-Hubbard model (the intensity of the static lattice potential determines the constants in the Bose-Hubbard model). This “native” Hamiltonian, with only on-site interactions, exhibits just two phases of matter: insulator and superfluid. Additional phases, such as a supersolid and density wave, are expected when nearest-neighbor interactions are added. Here we show preliminary results where we extend the “native” Bose-Hubbard Hamiltonian by rapidly varying the lattice potential.

9:48AM U32.00008 Topological defects and the 2D superfluid transition in S = 1 spinor condensates, SUBROTO MUKERJEE, CENKE XU, JOEL MOORE, UC Berkeley — Condensates of non-zero spin have recently attracted a lot of interest both theoretically and experimentally. The spin degree of freedom can give rise to interesting magnetically ordered phases. This talk will focus on condensates of Spin-1 atoms (23Na, 87Rb). These will be shown to have interesting ground state manifolds and topological defects. The topological defects play an important role in the superfluid transition in two dimensions. The low temperature phase of 23Na will be shown to be a spin disordered nematic superfluid of boson pairs. The superfluid transition is of the Kosterlitz-Thouless type but mediated by half vortices. Extensions of these ideas to higher spin systems will be discussed.

10:00AM U32.00009 Kosterlitz-Thouless physics in a one-dimensional optical lattice\textsuperscript{1}, ANIBAL IUCCI, University of Geneva, Switzerland, MIGUEL A. CAZALILLA, Donostia International Physics Center, Spain, THIERRY GIAMARCHI, University of Geneva, Switzerland — We study a system of quasi two-dimensional Bose gases formed in the nodes of a one-dimensional optical lattice potential. We focus on the effect of the tunneling of the atoms between adjacent planes on the Kosterlitz-Thouless crossover recently observed in the experiments of the Paris group [Z. Hadzibabic et al., Nature (London) 441, 1118 (2006)]. We compute the contrast of the interference pattern between two condensates, finding a behavior different from the one observed in the Kosterlitz-Thouless crossover. Finally, we consider the stack of a large number of pancakes.

\textsuperscript{1}We gratefully acknowledge financial from the Swiss National Science Foundation under MaNEP and Division II, and Gipuzkoako Foru Aldundia (Basque Country)

10:12AM U32.00010 Superfluid, Supersolid, and Phase Separation in Strongly Correlated Square Lattice Bosons, LIANG REN, ZIQIANG WANG, Department of Physics, Boston College — The Bose-Hubbard model and its mapping onto the quantum spin-1/2 XXZ model have played an important role in the understanding of the possible phases of strongly correlated lattice bosons. We present here a different mapping to the quantum spin-1/2 model in the hard-core limit and a mean field solution that accounts for both the direct and the exchange correlations on equal footing. We discuss the possible phase structure as a function of boson density, involving superfluid, supersolid, Neel solid, and phase separation, and make comparisons to the available quantum Monte Carlo simulations.

10:24AM U32.00011 Exotic Superconducting Phases of Ultracold Atom Mixtures on Triangular Lattices, SHAN-WEI TSAI, University of California, Riverside, LUDWIG MATHEY, Harvard University, ANTONIO H. CASTRO NETO, Boston University — We study two-dimensional Bose-Fermi mixtures of ultracold atoms on a triangular optical lattice, in the limit when the velocity of bosonic condensate fluctuations is much larger than the Fermi velocity\textsuperscript{1}. Interactions, lattice geometry and frustration lead to a rich phase diagram in this system. Using functional renormalization group techniques we show that this phase diagram contains exotic superconducting and spin-density wave phases. For spin-1/2 fermions on an isotropic lattice we find a competition of \( s-\), \( p-\), extended \( d-\), and \( f\)-wave symmetry, as well as antiferromagnetic order. For an anisotropic lattice, we further find an extended \( p\)-wave phase. A Bose-Fermi mixture with spinless fermions on an isotropic lattice shows a competition between \( p\) and \( f\)-wave symmetry.

\textsuperscript{1} L. Mathey, S.-W. Tsai, A.H. Castro Neto, cond-mat/0609212

10:36AM U32.00012 Temperature scale and Adiabatic Processes of Bosons in Optical Lattices, QI ZHOU, TIN-LUN HO, Ohio-State University — We show that as the optical lattice is ramped adiabatically in a Bose gas, the temperature first decreases in the superfluid regime due to kinetic effects, but eventually increases in the Mott regime due to interaction effects. We also show that in the Mott regime, the density profile of superfluid between Mott steps can be used as a temperature scale.

Thursday, March 8, 2007 11:15AM - 2:03PM — Session V32 DAMOP: Optical Lattices Colorado Convention Center 402

11:15AM V32.00001 Ion Chains in Optical Lattices as Simple Quantum Glasses, ROMAN SCHMIED, TOMMASO ROSCILDE, DIEGO PORRAS, IGNACIO CIRAC, Max Planck Institute for Quantum Optics — We propose the loading of linearly trapped ions onto an intense optical lattice. In the limit of a deep lattice, we recover a classical one-dimensional Coulomb lattice gas in a harmonic trap. This system exhibits glassiness, due to significant metastability in its translational degrees of freedom. Quantum fluctuations can be induced at will by lowering the lattice amplitude, which allows for the controlled realization of a quantum glassy system. We study the dynamics of such systems during thermal and quantum annealing, and discuss how the effects of glassiness can be observed in the currently available experimental ion-trap setups.

11:27AM V32.00002 Predicted quantum stripe ordering in optical lattices, CONGJUN WU, Kavli Institute for Theoretical Physics, University of California, Santa Barbara, California 93106, USA, W. VINCENT LIU, Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, Pennsylvania 15260, USA, JOEL MOORE, Department of Physics, University of California, Berkeley, California 94720, USA, SANKAR DAS SARMA, Condensed Matter Theory Center, Department of Physics, University of Maryland, College Park, Maryland 20742, USA — We predict the robust existence of a novel quantum orbital stripe order in the \( p\)-band Bose-Hubbard model of two-dimensional triangular optical lattices with cold bosonic atoms. An orbital angular momentum moment is formed on each site exhibiting a stripe order both in the superfluid and Mott-insulating phases. The stripe order spontaneously breaks time-reversal, lattice translation and rotation symmetries. In addition, it induces staggered plaquette bond currents in the superfluid phase.

Possible signatures of this stripe order in the time of flight experiment are discussed.

11:39AM V32.00003 BCS-BEC crossover on the two dimensional honeycomb lattice\textsuperscript{1}, ERHAI ZHAO, ARUN PARAMEKANTI, Department of Physics, University of Toronto — We study the attractive Hubbard model on a honeycomb lattice. At half-filling, we find a quantum critical point (QCP) separating a weakly interacting semimetal with massless Dirac fermions from a strong coupling \( s\)-wave superconducting state. Away from half-filling, this model exhibits a BCS-BEC crossover in the vicinity of this QCP. Studying this model using ultracold atoms in an optical lattice could shed light on quantum phase transitions and BCS-BEC crossovers in electronic models. We present results for the evolution of several observables through the BCS-BEC crossover at zero temperature — the Fermi surface, the superfluid density and the collective sound and Leggett modes. We also suggest a method to observe the Leggett mode in an optical lattice.

\textsuperscript{1}NSERC, Connaught Startup Grant, A.P. Sloan Foundation.

11:51AM V32.00004 Mixture of bosonic and spin-polarized fermionic atoms in an optical lattice, LODER POLLET, ETH Zurich, Switzerland, CORINNA KOLLATH, Universite de Geneve, Switzerland, ULRICH SCHOLLIWÖCK, RWTH Aachen University, Germany, MATTHIAS TROYER, ETH Zurich, Switzerland — We investigate the properties of Bose-Fermi mixtures for experimentally relevant parameters in one dimension using numerical methods. The effect of the fermions on the bosons is not only to deepen the parabolic trapping potential, but also to reduce the bosonic repulsion in higher order. This reduction would theoretically lead to an increase in the bosonic visibility. The opposite was observed however in the experimental \(^{87}\text{Rb}-^{40}\text{K}\) systems, most likely due to a sharp rise in temperature. We discuss the features which could be observed experimentally if temperature remains low, such as a bosonic Mott insulator transition driven by the fermionic concentration, and the formation of various composite particles.
12:03PM V32.00005 Coexistence of superfluid and Mott phases of strongly-interacting lattice bosons1. COURTNEY LANNERT, Wellesley College, ROMAN BARANKOV, SMITHA VISHVESHWARA, UIUC — Recent experiments on strongly-interacting bosons in optical lattices [1,2] have revealed the co-existence of spatially-separated Mott-insulating and number-fluctuating phases in the presence of an external trapping potential. Employing a simple theoretical model [3], we obtain an effective description of the superfluid state trapped between the Mott states. We calculate the collective excitation spectrum of such a superfluid and its critical temperature, and discuss the crossover between two- and three-dimensional behavior of its thermal properties as a function of the lattice parameters.


12:15PM V32.00006 Noise spectroscopy for detecting multi-atomic composite states in optical lattices1. HENNING MORITZ, Institute of Quantum Electronics, ETH Zurich, ANATOLY KUKLOV, CSI, CUNY — We propose and discuss methods for detecting quantum superpositions of multi-atomic composite fermion states in Bose-Fermi mixtures. We argue that, as an indirect indication of the composite fermions and a generic consequence of strong interactions, periodic correlations must appear in the atom shot noise of bosonic absorption images, similar to the bosonic Mott insulator1. The composites can also be detected directly and their quasi-momentum distribution measured. This method – an extension of the technique of noise correlation interferometry1 – relies on measuring higher order correlations between the bosonic and fermionic shot noise in the absorption images. The method is expected to work well for fermionic composites consisting of less than four atoms and for bosonic ones consisting of less than six atoms. Above these numbers, the uncorrelated noise becomes too large.

1 A.K. acknowledges support by NSF PHY-046814 grant.

1.03PM V32.00010 Quantum Monte Carlo simulations of resonantly interacting ultracold atoms1. VALY ROUSSEAU, PETER DENTENEER, Universiteit Leiden — A one-dimensional Hubbard-like model with a term describing conversion of fermionic-atom states into bosonic and vice versa is studied. The coupling between the fermionic atoms and the bosonic fluctuations of the condensate has similarities with electron-phonon couplings in crystals. The model is solved exactly by means of Quantum Monte Carlo simulations, which allow for the measurement of physical quantities of interest, such as the superfluid density and (quasi)condensate fraction. The calculated momentum distribution function is directly comparable with experiments.

12:27PM V32.00007 Dynamics of multicomponent Bose-Einstein condensates on two- and three-dimensional optical lattices1. R. MARK BRADLEY, Dept. of Physics, Colorado State University, Fort Collins, CO 80523 USA, L.D. CARR, J.E. BERNARD, Dept. of Physics, Colorado School of Mines, Golden, CO 80401 USA — Exact solutions to the mean field equations of motion are constructed for multicomponent Bose-Einstein condensates on square, rectangular and simple cubic optical lattices. For two condensates on a rectangular optical lattice, we find temporally-periodic solutions in which the optical lattice is divided into two sublattices, and the condensates oscillate back and forth between these sublattices. For a square optical lattice, a solution is found in which a single condensate moves in a checkerboard vortex-antivortex array. We also obtain fascinating solutions for two condensates in which the square optical lattice is divided into a total of four sublattices, and the condensates move cyclically between these sublattices. Stationary solutions of high symmetry are constructed for two, three and four condensates on a simple cubic optical lattice. Finally, the stability of the solutions in two dimensions is probed thorough numerical integrations of the mean field equations of motion.

12:39PM V32.00008 Analysis of the coherence time of a Bose-Einstein-condensate interferometer with optical control of dynamics1. JAMES STICKNEY, WPI, DANA Z. ANDERSON, JILA, University of Colorado and NIST, ALEX ZOZULYA, WPI — Atom interferometers using Bose-Einstein condensate that is confined in a waveguide and manipulated by optical pulses have been limited by their short coherence times. We present a theoretical model that offers a physically simple explanation for the loss of contrast and propose the method for increasing the fringe contrast by recombining the atoms at a different time. A simple, quantitatively accurate, analytical expression for the optimized recombination time is presented and used to place limits on the physical parameters for which the contrast may be recovered.

12:51PM V32.00009 Pairing and density-wave phases in Fermion-Boson mixtures at fixed filling1. FILIPPOS KLIRONOMOS, SHAN-WEN TSAI, University of California, Riverside — We study a mixture of fermionic and bosonic cold atoms on a two-dimensional optical lattice, where the fermions are prepared in two hyperfine (isospin) states and the bosons have Bose-Einstein condensed (BEC). The coupling between the fermionic atoms and the bosonic fluctuations of the BEC has similarities with electron-phonon couplings in crystals. We study the phase diagram for this system at fixed fermion density of one per site (half-filling). We find that tuning of the lattice parameters and interaction strengths (for fermion-fermion, fermion-boson and boson-boson interactions) drives the system to undergo antiferromagnetic ordering, s-wave and d-wave pairing superconductivity or a charge density wave phase. We use functional renormalization group analysis where retardation effects are fully taken into account by keeping the frequency dependence of the the interaction vertices and self-energies. We calculate response functions and also provide estimates of the energy gap associated with the dominant order, and how it depends on different parameters of the problem.

1:03PM V32.00011 Quantum Monte Carlo simulations of resonantly interacting ultracold atoms1. MASAHIKO MACHIDA, Japan Atomic Energy Agency, YOJI OHASHI, Keio University, HIDEKI MATSUMOTO, Tsukuba University, SUSUMU YAMADA, Japan Atomic Energy Agency — We systematically investigate ground state properties and effects of an optical lattice potential in one- and two-dimensional two-component trapped Fermi gases with the same population. Using an exact diagonalization method and a density-matrix renormalization group technique, we calculate the ground state many-body wave-function, as well as the density profile, as a function of the strength of an attractive interaction. We show that fine inhomogeneous zigzag patterns universally emerge in the above models under the presence of attractive on-site interaction and trap potential. Theoretical and numerical analyses suggest that these structures originate from an effective repulsive interaction between tightly-bound pairs and a breakdown of translational invariance. Furthermore, it is emphasized that the pattern obtained numerically in the 2-D model is the checkerboard type, which is very similar to results recently observed in a vortex core of High-Tc cuprate superconductor. In the presentation, we will touch imbalanced cases, too.
1:27PM V32.00012 Two Critical velocities for a superfluid in a periodic potential. BIAO WU, JUNREN SHL, Institute of Physics, Chinese Academy of Sciences, Beijing, China — In contrast to a homogeneous superfluid which has only one critical velocity, there exist two critical velocities for a superfluid in a periodic potential. The first one, which we call inside critical velocity, is for a macroscopic impurity to move frictionlessly in the periodic superfluid system; the second, which is called trawler critical velocity, is the largest velocity of the lattice for the superfluidity to maintain. The result is relevant to the superfluidity observed in the Bose-Einstein condensate in an optical lattice and supersolid helium.

1:39PM V32.00013 Finite-size effects and entanglement in ultracold atoms on optical lattices1, L. D. CARR2,3, R. C. BROWN2,3, D. G. SCHIRMER2,3, R. V. MISHMASH2, S. P. SANTOS2, 2Physics Department, Colorado School of Mines, Golden, CO 80401, USA, I. DANSHITA1, J. E. WILLIAMS2, CHARLES W. CLARK2, 3Electron and Optical Physics Division, National Institute of Standards and Technology, Gaithersburg, Maryland 20899, USA — We study finite size effects in the phase diagrams of a number of Fermi-, Bose-, and Fermi-Bose-Hubbard Hamiltonians relevant to ultracold atoms in one dimension. Both exact numerical solutions and approximations via Vidal’s algorithm (Time Evolving Block Decimation) are utilized. We characterize excited states by their entanglement, in particular comparing three entanglement measures: the entropy of entanglement, Meyer’s Q-measure, and the Schmidt number. We show that the phase diagrams and the entanglement structure of excited eigenstates as a function of the Hamiltonian parameters depends strongly on the number of sites and the dimensionality of on-site Hilbert space. These results are vital for experiments on small systems, as they differ greatly from what is found in the thermodynamic limit.

1We gratefully acknowledge support of the NSF.

1:51PM V32.00014 Quantum Entangled Dark Solitons in the Bose-Hubbard Model1, R.V. MISHMASH, L.D. CARR, Physics Department, Colorado School of Mines — We investigate the existence and stability of dark quantum solitons formed by Bose-Einstein condensates in a one-dimensional optical lattice. This is done by employing a one-level Bose-Hubbard model and simulating the real time dynamics of the condensate using both exact numerical techniques and Vidal’s simulation method, i.e., Time Evolving Block Decimation. For the initial condition, we take a Gutzwiller ansatz wavefunction with on-site truncated coherent states and build a direct quantum analog to the soliton solutions of the Discrete Nonlinear Schrödinger Equation. The stability of these solutions are then analyzed in the Bose-Hubbard model for different parameter regimes. We are especially interested in the behavior of dark solitons near the Mott-superfluid border. Also, we quantitatively examine the effect of quantum entanglement on dark quantum soliton stability.

1We gratefully acknowledge support from the National Science Foundation.

Thursday, March 8, 2007 2:30PM - 5:30PM –
Session W32 DAMOP: Bose-Einstein Condensation in Trapped Atomic Gases Colorado Convention Center 402

2:30PM W32.00001 ABSTRACT WITHDRAWN –

2:42PM W32.00002 Collective Excitations of a Two-Component Bose Condensate at Finite Temperature1, CHANG-HUA ZHANG, Indiana University-Purdue University Indianapolis, HERBERT A. FERTIG, Indiana University — We compare the collective modes for Bose-condensed systems with two degenerate components with and without intercomponent coherence at finite temperature using the time-dependent Hartree-Fock approximation. We show that the interaction between the condensate and non-condensate in these two cases results in qualitatively different collective excitation spectra. We show that at zero temperature the single-particle excitations of the incoherent Bose condensate can be probed by intercomponent excitations.

1This work was supported by the NSF Grant No. DMR0454699

2:54PM W32.00003 ABSTRACT HAS BEEN MOVED TO B21.00008 –

3:06PM W32.00004 Dispersive Shock Wave Collisions in Bose-Einstein Condensates and Light1, MARK HOEFER, National Institute of Standards and Technology, MARK ABLowitz, Applied Math Department, University of Colorado, Boulder — When two classical shock waves collide, the interaction is relatively simple and is explained by classical hyperbolic system theory and jump/entropy conditions. An analogous theory for the interaction of two dispersive shock waves (DSWs) is presented. Two cases will be considered: i) a collision where two DSWs are propagating directly toward one another, ii) merging where a faster DSW overtakes a slower one. It is shown that, after a complicated quasi-periodic or multi-phase region is created, the DSW interaction process results in: i) two single DSWs propagating away from one another in the collision case, ii) a single, larger DSW representing the merger of the original two DSWs in the merging case. Remarkably, these results coincide exactly with their classical shock wave counterpart. These results have direct application to Bose-Einstein condensates and nonlinear optics.

3:18PM W32.00005 Effects of Disorder on a Bose-Einstein Condensate with Tunable Interaction: Transition to an Insulator and Loss of Phase Coherence11, YONG P. CHEN, J. HITCHCOCK, D. DRIES, M. JUNKER, C. WELFORD, R.G. HULET, Department of Physics and Astronomy and Rice Quantum Institute, Rice University, Houston TX 77005 USA — We report our study of the effects of disorder on a Bose-Einstein condensate (BEC) of ^7Li atoms with tunable interaction. A large ^7Li BEC is created in an elongated optical trap after forced evaporation. The strength of the repulsive interaction is tuned using a magnetic Feshbach resonance. A disordered optical potential, whose strength is also tunable, is generated by projecting a laser speckle pattern onto the atoms. We have performed transport studies by measuring the center of mass motion of the trapped BEC in the presence of disorder. Beyond a disorder strength (1), the dipole oscillation of the superfluid BEC is completely suppressed, signaling a transition to an insulator. We have also studied the time of flight expansion of the BEC after release from the trap and disorder potentials. With intermediate disorder strengths, striking fringes appear in the cloud after sufficient expansion time. Beyond some disorder strength (Vp), comparable to the chemical potential of the trapped BEC, the fringes are washed out, signaling a loss of phase coherence. Interestingly, Vp is significantly larger than Vc, suggesting that finite phase coherence can still exist in the insulator.

1Supported by NSF, ONR, NASA and the Welch Foundation.
such systems by including the contributions of quantum fluctuations that seed the eventual formation of ferromagnetic domains. We will give a simple quantum

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S=1 atoms in the context of

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the experimental data.

coupled time–dependent (TD) Gross–Pitaevskii (GP) equations. As initial states we used Thomas–Fermi approximate solutions of the time–independent GP

trap. An external magnetic field using a Feshbach resonance enabled tuning of the 85–85 scattering length. Density profiles were obtained by taking absorption

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an important role in conversion efficiencies. Maximum conversion efficiencies are determined by quantum statistics and the number ratio. When the major

Feshbach molecule in population imbalanced atomic gases, extending the recent work [J. E. Williams et. al., New J. Phys. 8, 150 (2006)] on the Feshbach

University of Tokyo, JAMES E. WILLIAMS, Wolfram Research, Inc., TETSURO NIKUNI, Tokyo University of Science — We study formations of heteronuclear

associated with the complex mode in the context of Kubo’s linear response theory.

eigenstate of the complex mode sector of the unperturbed Hamiltonian. Finally, we discuss the instability of the condensates caused by the quantum fluctuation

the operators associated with the complex modes, which are simply neither bosonic nor fermionic ones. Next, to evaluate physical quantities, we construct the

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quantum fluctuation in the case that these equations have complex eigenvalues. First, to expand quantum field which represents the quantum fluctuation, we

the unperturbed Hamiltonian, and the quasi-particle picture, which describes the quantum fluctuation around the condensates, is obtained. We consider the

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the unperturbed Hamiltonian, and the quasi-particle picture, which describes the quantum fluctuation around the condensates, is obtained. We consider the quantum fluctuation in the case that these equations have complex eigenvalues. First, to expand quantum field which represents the quantum fluctuation, we give the complete set including pairs of complex modes whose eigenvalues are complex conjugate to each other. The expansion of the quantum field brings the operators associated with the complex modes, which are simply neither bosonic nor fermionic ones. Next, to evaluate physical quantities, we construct the eigensate of the complex mode sector of the unperturbed Hamiltonian. Finally, we discuss the instability of the condensates caused by the quantum fluctuation associated with the complex mode in the context of Kubo’s linear response theory.

This work supported in part by the U.S. National Science Foundation

3:30PM W32.00006 Quantum Accelerator Modes in BEC, VIJAYASHANKAR RAMAREDDY, Oklahoma State University, GHAZAL BEHIN-AEIN, PEYMAN AHMADI, GIL SUMMY — The quantum delta kicked accelerator can be realized by subjecting cold atoms to spatially corrugated off resonant pulses of light. These standing wave pulses are applied in the direction in which there is a component of gravity and result in acceleration of a group of atoms. For the first time we observed Quantum Accelerator Modes (QAM) in BEC. We show that using the narrow momentum distribution of BEC, the structures in phase space map produced by a pseudo classical theory can be directly studied. We show that QAMs can be efficiently populated using BEC. Details will be presented.

3:42PM W32.00007 Density Profiles of 85Rb–87Rb Binary Mixtures2, LAURA HALMO, ALISON LOTA, MARK EDMWARDS, Georgia Southern University, SCOTT PAPP, DEBORAH JIN, JILA — We have studied the density distribution of binary mixtures of 87Rb and 85Rb Bose–Einstein condensates under conditions similar to a recent experiment conducted in the Jin Group at JILA. In this experiment, a binary mixture of the two Rb isotopes were confined in a magnetic trap and rf evaporative cooling was carried out on the 87Rb causing sympathetic cooling of the 85Rb. This mixture was then transferred to an optical trap to minimize 85Rb 3–body loss and condensation was achieved by slowly decreasing the depth of the optical trap. An external magnetic field using a Feshbach resonance enabled tuning of the 85–85 scattering length. Density profiles were obtained by taking absorption images of expanded condensates after releasing them from the trap. We have calculated the theoretical shape of such images by solving approximately the coupled time–dependent (TD) Gross–Pitaevskii (GP) equations. As initial states we used Thomas–Fermi approximate solutions of the time–independent GP equation and approximately solved the time–dependent Gross–Pitaevskii equation to model the expansion. We present a comparison of this calculation with the experimental data.

3:54PM W32.00008 Bose-Einstein S=1 Spinor Condensates, Dynamics, Noise Statistics and Scaling, GEORGE I. MIAS, STEVEN M. GIRVIN, Yale University — We examine Bose-Einstein spinor condensates in the short-time non-linear regime for S=1 atoms in the context of 87Rb studied experimentally by the Stamper-Kurn group [L. Sadler et al, Nature 443, p193, 2006]. We will describe the quantum dynamics of a sample that starts as a condensate of N atoms in a pure S = 1, m_f = 0 state. Our approach seeks to improve the mean-field description of such systems by including the contributions of quantum fluctuations that seed the eventual formation of ferromagnetic domains. We will give a simple quantum description of the system for the short-time regime in analogy with “two-mode squeezing” of quantum optics, treating the initial m_f = 0 condensate as a source for the conversion to pairs of m_f = 1, –1 states. Even though the system as a whole is described by a pure state with zero entropy, the reduced density matrix for the m_f = +1 degree of freedom, obtained by tracing out the m_f = –1, 0 degrees of freedom, is a thermal state. We propose to observe the large fluctuations associated with this thermal state using Hanbury-Brown-Twiss noise correlation measurements in the density and momentum distributions of the individual m_f species. Finally, we will discuss the effect of excitations in connection to the seeding and ultimate formation of domains of ferromagnetically aligned spins. (Supported by NSF DMR-0603369).

4:06PM W32.00009 Nonlinear quantum hydrodynamics in Bose-Einstein condensates, PETER ENGELS, COLLIN ATHERTON, Washington State University — Bose-Einstein condensates are quantum fluids governed by nonlinear interatomic interactions. They provide an excellent tool to study intriguing phenomena in the field of nonlinear hydrodynamics. We will report on hydrodynamics experiments carried out in a newly constructed BEC apparatus at Washington State University, Pullman. Current research directions include quantum shock waves and parametric resonances. We will describe the current results and future directions.

4:18PM W32.00010 Quantum Field Theoretical Description of Dynamical Instability of Trapped Bose-Einstein Condensates, MAKOTO MINE, Department of Physics, Waseda University, MASAHIKO OKUMURA, Department of Applied Physics, Waseda University, TOMOKA SUNAGA, Department of Physics, Waseda University, YOSHIYA YAMANAKA, Department of Materials Science and Engineering, Waseda University — The Bogoliubov-de Gennes equations are used for a number of theoretical works on the trapped Bose-Einstein condensates. Particularly, it is important that if all of the eigenvalues of the equations are real, the solutions of the equations diagonalize the unperturbed Hamiltonian, and the quasi-particle picture, which describes the quantum fluctuation around the condensates, is obtained. We consider the quantum fluctuation in the case that these equations have complex eigenvalues. First, to expand quantum field which represents the quantum fluctuation, we give the complete set including pairs of complex modes whose eigenvalues are complex conjugate to each other. The expansion of the quantum field brings the operators associated with the complex modes, which are simply neither bosonic nor fermionic ones. Next, to evaluate physical quantities, we construct the eigensate of the complex mode sector of the unperturbed Hamiltonian. Finally, we discuss the instability of the condensates caused by the quantum fluctuation associated with the complex mode in the context of Kubo’s linear response theory.

4:30PM W32.00011 Conversion efficiency of heteronuclear Feshbach molecules, SHOEI WATABE, the University of Tokyo, JAMES E. WILLIAMS, Wolfram Research, Inc., TETSURO NIKUNI, Tokyo University of Science — We study formations of heteronuclear Feshbach molecule in population imbalanced atomic gases, extending the recent work [J. E. Williams et. al., New J. Phys. 8, 150 (2006)] on the Feshbach molecule formation. We find that conversion efficiency depends on a ratio of the number of atomic species in the initial state before the magnetic sweep, as well as an initial temperature and an initial peak phase space density. At low temperature in quantum degenerate regime, quantum statistics of atoms plays an important role in conversion efficiencies. Maximum conversion efficiencies are determined by quantum statistics and the number ratio. When the major component is bosonic, the maximum conversion efficiency is 50%. On the other hand, when the major component is fermionic and the minor component is bosonic, the maximum conversion efficiency has a range from 50% to 100%, which is determined by the initial atomic ratio. In the case that both components are fermionic, the maximum conversion efficiency is 100%. In the region where the gases does not condense, the conversion efficiency is described as a function of initial peak phase space density of a major component.

4:42PM W32.00012 Using modified Gaussian distribution to study the physical properties of one and two-component ultracold atoms1, CHOJ-CHUN HUANG, WEN-CHIN WU, National Taiwan Normal University — Gaussian distribution is commonly used as a good approximation to study the trapped one-component Bose-condensed atoms with relatively small nonlinear effect. It is not adequate in dealing with the one-component system of large nonlinear effect, nor the two-component system where phase separation exists. We propose a modified Gaussian distribution which is more effective when dealing with the one-component system with relatively large nonlinear terms as well as the two-component system. The modified Gaussian is also used to study the breathing modes of the two-component system, which shows a drastic change in the mode dispersion at the occurrence of the phase separation. The results obtained are in agreement with other numerical results.

1Financial support from the National Science Council of Taiwan
5:06PM W32.00014 Modeling the Expansion of Bose–Einstein Condensate Mixtures in the Thomas–Fermi Limit¹. ALISON LOTA, LAURA HALMO, CHARLES HOLCOMBE, MARK EDWARDS, Georgia Southern University — We have studied the expansion of a mixture of $^{85}$Rb–$^{87}$Rb Bose–Einstein condensates within the Thomas–Fermi approximation. Systems involving mixtures of Bose–Einstein condensates of different atomic species can be accurately modeled by coupled Gross–Pitaevskii equations. As for single condensates, the coupled Gross–Pitaevskii equations can be written in hydrodynamic form where each condensate is described by a density and phase. Also just as for single condensates, the hydrodynamic equations of motion for condensate mixtures reduce to classical equations of motion when their quantum pressure terms are neglected (Thomas–Fermi approximation). In this case, it is possible to find time–dependent Thomas–Fermi approximate solutions for the hydrodynamic equations of motion for mixtures. We present these equations and their solution for the particular case of a $^{85}$Rb–$^{87}$Rb expansion that occurred in a recent experiment performed in the Jin group at JILA. We also highlight interesting features that can occur because of interaction effects in the expansion of multiple–condensate mixtures.

¹Work sponsored in part by the U.S. National Science Foundation

5:18PM W32.00015 ABSTRACT WITHDRAWN —

8:00AM X32.00001 Decoherence dynamics in low-dimensional cold atoms condensates ANTON BURKOV, MIKHAIL LUKIN, EUGENE DEMLER, Harvard University — We report on a theoretical study of the dynamics of decoherence of a matter-wave interferometer, consisting of a pair of low-dimensional cold atoms condensates. We identify two distinct regimes in the time dependence of the coherence factor of the interferometer: quantum and classical. Explicit analytical results are obtained in both regimes. In particular, in two-dimensional (2D) condensates in the classical (long time) regime, we find that the dynamics of decoherence is universal, exhibiting a power-law decay with an exponent proportional to the ratio of the temperature to the Kosterlitz-Thouless temperature of a single 2D condensate. In the one-dimensional (1D) case we find a nonanalytic time dependence of decoherence, which is a consequence of the nonhydrodynamic nature of damping in 1D liquids.

8:12AM X32.00002 Crossover to a quasi-condensate in a weakly interacting trapped 1D Bose gas KAREN KHERUNTSYAN, University of Queensland, ISABELLE BOUCHOULE, Laboratoire Charles Fabry, UMR 8501 du CNRS, GORA SHLYAPNIKOV, Universite Paris-Sud XI — One-dimensional (1D) Bose gases are remarkably rich physical systems exhibiting properties not encountered in 2D or 3D. Here we study the exactly solvable 1D model of bosons interacting via a repulsive delta-function potential. Specifically, we discuss the system in the context of a harmonically trapped, weakly interacting 1D Bose gas at ultra-low temperatures and analyze the transition from a fully decoherent regime to a coherent, quasi-condensate regime. By finding the characteristic critical temperature and atom number that depend explicitly on the interaction strength and the trap frequency, we specify the conditions for identifying this transition as an interaction-induced crossover. We contrast this to the finite-size Bose-Einstein condensation (BEC) phenomenon studied previously in the context of an ideal trapped 1D Bose gas. We predict that for sufficiently weak confinement one expects to observe the interaction-induced crossover scenario, rather than the finite-size BEC. The situation is reversed for strong confinement. We identify typical experimental parameters that enable the realization of either of these two competing scenarios.

8:24AM X32.00003 Quantum Monte Carlo study of a 1D phase-fluctuating condensate CHARLOTTE GILS, LODIE POLLET, ETH Zurich, ALICE VERNIER, FREDERIC HEBERT, GEORGE BATROUNI, University of Nice, MATTHIAS TROYER, ETH Zurich — Starting from a microscopic description, we numerically investigate the low temperature behaviour of a trapped one dimensional Bose gas with repulsive interactions. For a sufficient number of particles and weak interactions, we identify a pronounced quasicondensate regime in temperature, where density fluctuations are negligible while phase fluctuations are considerable. In the weakly interacting limit, we find good agreement of our results with those obtained using a mean-field approximation. In addition, we study the system in parameter regimes which are beyond the accessibility of mean-field approaches. A phase-fluctuating condensate exists also in these cases, but phase-correlation properties are qualitatively different.

8:36AM X32.00004 Spin dynamics in the two-component strongly repulsive 1D Bose gas MIKHAIL ZVONAREV, THIERRY GIAMARCHI, University of Geneva, VADIM CHEIANOV, University of Lancaster — We investigate spin diffusion in the two-component one-dimensional Bose gas in the limit of strong repulsion. While the spectrum of charge excitations can be linearized in such a system, it remains quadratic in the spin sector, and the Luttinger-Liquid description is not applicable. However, we showed that dynamical Green’s functions of the system can still be found by using a mapping onto an effective spinless model. In this way we get an exact analytic expression for the one-particle and spin-spin Green’s functions and found an anomalously low spin-diffusion rate.

8:48AM X32.00005 Dynamical correlation functions of the 1D Bose gas (Lieb Liniger model) JEAN-SEBASTIEN CAUX, PASQUALE CALABRESE, Universiteit van Amsterdam — The momentum- and frequency-dependent correlation functions (one-body and density-density) of the one-dimensional interacting Bose gas (Lieb-Liniger model) are obtained for any value (repulsive or attractive) of the interaction parameter. In the repulsive regime, we use the Algebraic Bethe Ansatz and the ABACUS method to reconstruct the correlators to high accuracy for systems with finite but large numbers of particles. For attractive interactions, the correlations are computed analytically. Our results are discussed, with particular emphasis on their applications to quasi-one-dimensional atomic gases.
a glassy phase. Increasing the intraspecies repulsion for the fast bosons drives them through a quantum phase transition to the superfluid state.

to the other one, effectively localizing it. Quantum Monte Carlo investigations reveal an extremely slow relaxation of the system towards equilibrium, typical of quantum emulsion states can be regarded as the out-of-equilibrium realization of a localization phenomenon, in which each species acts as a random potential quantum emulsion act as an effective potential to the faster ones. When the interspecies repulsion is strong compared with the intraspecies one, a phase-separated ground state.

boson mixtures in one-dimensional optical lattices, targeting their ground state either by slow cooling from high temperature, or by a slow change in the temperature of the lattice.  

Damping of dipole oscillations of a Bose condensate in a 1D optical lattice at finite temperatures.  

A glassy phase. Increasing the intraspecies repulsion for the fast bosons drives them through a quantum phase transition to the superfluid state.

**Strongly correlated bosons on optical superlattices: Dynamics and relaxation in the superfluid and insulating regimes**

- **MARCOS RIGOL, MAXIM OLSHANII**, University of Southern California, ALEJANDRO MURAMATSU, University of Stuttgart — We study the nonequilibrium dynamics of hard-core bosons (HCB's) on one-dimensional lattices. The dynamics is analyzed after a sudden switch-on or switch-off of a superlattice potential, which can bring the system into insulating or superfluid phases, respectively. A collapse and revival of the zero-momentum peak can be seen in the first case. We study in detail the relaxation of these integrable systems towards equilibrium. We show that after relaxation time averages of physical observables, like the momentum distribution function, can be predicted by means of a generalization of the Gibbs distribution. [M. Rigol, A. Muramatsu, and M. Olshanii, Phys. Rev. A 74, 053616 (2006)].

**Spectroscopy and quantum quench dynamics of interacting one-dimensional Bose condensates**

- **VLADIMIR GRITSEV, Harvard University, ANATOLI POLKOVNIKOV, Boston University, EUGENE DEMLER, Harvard University** — We discuss applications of the exact solution of the quantum sine Gordon model to study non equilibrium dynamics of two coupled interacting one dimensional Bose liquids. In particular, we consider a set up in which a sudden quench of the tunneling amplitude introduces oscillations in the relative phase of the two condensates. We demonstrate that the power spectrum of the interference amplitude oscillations should reveal the non trivial excitation spectrum of the quantum sine Gordon model.

**Onset of Chaos and Thermalization in a One-Dimensional Bose-Hubbard Lattice in the Mean-Field Regime**

- **DOUGLAS MASON, AMY CASSIDY, VANJA DUNKO, MAXIM OLSHANII**, University of Southern California — The goal of this work is to identify a Chirikov threshold for the onset of chaos and, beyond the threshold, to study thermalization in a one-dimensional Bose-Hubbard Model. In the mean-field approximation the problem is conceptually close to the one of the beta-f Fermi-Pasta-Ulam model. In the regime of well developed chaos the atomic momentum distribution is shown numerically to converge to the predictions of the grand canonical ensemble, simulated in turn using the Monte Carlo method. We find good agreement between our analytical predictions and the results of our numerical calculations. We discuss the relevance of our results to the recent Newton’s Cradle experiments on relaxation of an ensemble of bosonic atoms in a one-dimensional optical trap [T. Kinoshita, T. Wenger, D.S. Weiss, Nature (London) 440, 900 (2006)].

**Dynamics of Bose gases in Y-shaped potential and Andreev-type reflection**

- **AKIYUKI TOKUNO, Tokyo Institute of Technology, MASAKI OSHIKAWA, Institute for Solid State Physics, EUGENE DEMLER, Harvard University** — Recently, guiding of atoms in low-dimensional magnetic traps has been actively studied. While the theory of one-dimensionally trapped atoms has been vigorously studied, much of the dynamical aspects remain unexplored. As a simple yet nontrivial example, we study the real-time dynamics of BEC in the Y-shaped potential. Collective nature of the transport is considered by treating each one-dimensional channel as a Tomonaga-Luttinger liquid. We analytically investigate the reflection and transmission at the center of the potential, for a high-density packet moving from one side to the other side. Even though we study a system of bosons, we find that the reflection at the center of the potential exhibits an Andreev-type reflection reminiscent of that at a normal-superconductor interface in electron systems. This could be attributed to the fermionic nature of the repulsively interacting Bose systems in one dimension. In addition, we shall also discuss the dynamics in the ring type interferometer which consists of two symmetric Y-junction.

**Damping of condensate oscillations of a trapped Bose condensate in a 1D optical lattice at finite temperatures**

- **EMIKO ARAHATA, TETSURO NIKUNI, Tokyo University of Science, ALEXANDER MURAMATSU, University of Stuttgart**, Institute for Solid State Physics, EUGENE DEMLER, Harvard University — We study Landau damping of dipole oscillations of a Bose condensate in a 1D optical lattice at finite temperatures. Assuming that an additional trap potential is highly anisotropic, in which the radial confinement is much tighter than the axial confinement, we derive a quasi-1D model of the Gross-Pitaevskii equation and the Bogoliubov equations that include the effect the excitations in the radial direction. We calculate the Landau damping rate and investigate its dependence on the lattice depth, compare our result with the experimental data on collective modes in an optical lattice [F. Ferlaino et al., Phys. Rev. A 66, 011604(2002)].

**Glassy behavior of Bose-Bose mixtures in one-dimensional optical lattices**

- **IGNACIO CIRAC, TOMMASO ROSCILDE, Max-Planck Institute for Quantum Optics** — We investigate the properties of strongly repulsive two-boson mixtures in one-dimensional optical lattices, targeting their ground state either by slow cooling from high temperature, or by a slow change in the Hamiltonian parameters starting from the weakly interacting regime. The two bosonic species have very different effective masses, so that the slow bosons can act as an effective potential to the faster ones. When the interspecies repulsion is strong compared with the intraspecies one, a phase-separated ground state is masked by an exponentially large number of metastable quantum emulsion states, in which the two species are fragmented into microscopic droplets. The quantum emulsion states can be regarded as the out-of-equilibrium realization of a localization phenomenon, in which each species acts as a random potential to the other one, effectively localizing it. Quantum Monte Carlo investigations reveal an extremely slow relaxation of the system towards equilibrium, typical of a glassy phase. Increasing the interspecies repulsion for the fast bosons drives them through a quantum phase transition to the superfluid state.
8:00AM X33.00001 Quantum simulation of magnetism using optical lattices1, BRIAN DEMARCO, UIUC — Physical simulation as a means for resolving outstanding quantum many-body problems was first proposed by Feynmann in 1981. Since then, physicists have dreamed of using physical quantum simulation as a quantitative tool. Ultra-cold atoms trapped in an optical lattice are now emerging as an ideal tool for quantum simulation of a wide range of many-body quantum models, including the Hubbard model and quantum magnetism. I will review the developing field of quantum simulation using ultra-cold atoms and highlight our progress on simulating quantum magnetism.

1supported by the ONR, NSF, and Sloan Foundation

8:36AM X33.00002 Quantum phase transitions of light, CHARLES TAHAN, Cavendish Laboratory, University of Cambridge (UK), ANDREW GREENTREE, JARED COLE, LLOYD HOLLEMBERG, University of Melbourne (AU) — Recently, condensed matter and atomic experiments have reached a length-scale and temperature regime where new quantum collective phenomena emerge. Finding such physics in systems of photons, however, is problematic, as photons typically do not interact with each other and can be created or destroyed at will. Here, we introduce a physical system of photons that exhibits strongly correlated dynamics on a meso-scale. By adding photons to a two-dimensional array of coupled optical cavities each containing a single two-level atom in the photon-blockade regime, we form dressed states, or polaritons, that are both long-lived and strongly interacting. Our zero temperature results predict that this photonic system will undergo a characteristic Mott insulator (excitations localised on each site) to superfluid (excitations delocalised across the lattice) quantum phase transition. Each cavity’s impressive photon out-coupling potential may lead to actual devices based on these quantum many-body effects, as well as observable, tunable quantum simulators. We explicitly show that such phenomena may be observable in micro-machined diamond containing nitrogen-vacancy colour centres and superconducting microwave strip-line resonators. (Nature Physics, December 2006)

8:48AM X33.00003 Universal and measurable entanglement in the spin-boson model, ANGELA KOPP, KAYAN LE HUR, HARRY ANDERSON, University of Copenhagen, — We study the entanglement between a qubit and its environment by calculating the von Neumann entropy of the spin in the delocalized phase of the spin-boson model. Using a well-known mapping between the spin-boson model with Ohmic dissipation and the anisotropic Kondo model, we obtain exact results for the entanglement entropy $E$ at arbitrary dissipation strength $\alpha$ and level asymmetry $\gamma$. We show that the Kondo energy scale $T_K$ controls the entanglement between the qubit and the bosonic environment. For $h \ll T_K$, we find that $E = E(h = 0) - 2h^2/(2 - 2\alpha)(1 + 1/(2 - 2\alpha))2\pi \ln(\Gamma[1 + 1/(2 - 2\alpha)])$, where $\gamma = \alpha \ln(\alpha + 1 - \alpha) \ln(1 - \alpha)$. The universal $(h/T_K)^2$ scaling reflects the Fermi liquid nature of the Kondo ground state. In the limit $h \gg T_K$, $E$ vanishes as $(T_K/h)^{2-\alpha} \ln(\alpha + 1 - \alpha)$. We thoroughly explore the phase space $(\alpha, h)$ for a given $h$, the maximal entanglement occurs in the crossover regime $h \sim T_K$. We also emphasize the possibility of measuring this entanglement using charge qubits subject to electromagnetic noise.

9:00AM X33.00004 Quantum Information Transport in Nuclear Spin Chains, PAOLA CAPPELLARO, ITAMP-Harvard University and Smithsonian Astrophysical Observatory, Cambridge, MA 02138, USA, DAVID CORY, Massachusetts Institute of Technology, — In a Cooper-pair box realization of a qubit, the energy splitting $\xi$ is a characteristic Mott insulator (excitations localised on each site) to superfluid (excitations delocalised across the lattice) quantum phase transition. Each cavity’s impressive photon out-coupling potential may lead to actual devices based on these quantum many-body effects, as well as observable, tunable quantum simulators. We explicitly show that such phenomena may be observable in micro-machined diamond containing nitrogen-vacancy colour centres and superconducting microwave strip-line resonators. (Nature Physics, December 2006)

9:12AM X33.00005 Cavity QED in the mesoscopic regime, PASCAL DEGIOVANNI, ENS Lyon and Boston University, — We report on a recent study of the behavior of N atoms resonantly coupled to a single electromagnetic field mode sustained by a high-Q cavity, containing a mesoscopic coherent field. Using a simple effective Hamiltonian model, we show that the strong coupling between the cavity and N atoms/qubits produces an atom-field entangled state, involving N+1 nearly coherent components slowly rotating at different paces in the phase plane. The periodic overlap of these components results in a complex collapse and revival pattern for the Rabi oscillation. Decoherence induced by cavity relaxation, qubit relaxation and dephasing are taken into account. We propose a simple model based on the stochastic quantum trajectories approach. Its results are successfully compared to numerical simulations. Explicit predictions for Rydberg atoms and circuit QED experiments are obtained and suggest that these effects may be observable in the near future.

9:24AM X33.00006 Diverging Length Scale, Scaling, and Universality of Entanglement Near a Quantum Phase Transition, HAN-DONG CHEN, UIUC — In this work, we show that an important quantity to study about entanglement near a quantum phase transition is the two-body entanglement $S(i,j)$, which measures the entanglement between two separated degrees of freedom $(i,j)$ and the rest of the system. We establish its relation to correlation functions in the long range limit. Away from the critical point, $S(n)$ saturates with a characteristic length scale $\xi_E$, as the distance $n$ increases. The entanglement length $\xi_E$ diverges near the critical point with the same critical exponent as correlation length. At the critical point, $S(n)$ follows a power law. The universality and finite size scaling of entanglement are demonstrated in a class of exactly solvable spin model.

9:36AM X33.00007 Landau-Zener dynamics in qubits-oscillator settings, SIGMUND KOHLER, MARTIJN WUBS, PETER HÄNGGI, Institut für Physik, Universität Augsburg, Germany, KEIJI SAITO, Department of Physics, Tokyo University, Japan, YOSUKE KAYANUMA, Department of Mathematical Science, Osaka Prefecture University, Japan — In a Cooper-pair box realization of a qubit, the energy splitting of the logical states can be tuned upon variation of the penetrating magnetic flux. Then the coupling of the qubit to a circuit QED oscillator can induce Landau-Zener transitions between the qubit levels. By summing a perturbation series to all orders, we obtain an exact expression for the corresponding LZ transition probability. Moreover, we determined the parameters for which a non-adiabatic transition is accompanied by single-photon generation and showed that LZ transitions can create qubit-oscillator entanglement in a controlled manner. Replacing the oscillator by a quantum heat bath, we encounter a nontrivial problem of dissipative quantum mechanics which can be solved in a similar manner. As a main application, we discuss the determination of both the reorganization energy and the integrated spectral density of the bath. Moreover, this provides a convenient test bench for numerical schemes for real-time dissipative quantum dynamics.

9:48AM X33.00008 Coherence control via dynamical decoupling of an electron spin in a quantum dot. WENXIAN ZHANG, V.V. DOBROVITSKI, NIKOLAOS Konstantinidis, Ames Laboratory, Iowa State University, Ames, Iowa 50011, USA, LEA F. SANTOS, LORENZA VIOLA, Department of Physics and Astronomy, Dartmouth College, Hanover, New Hampshire 03755, USA, B.N. HARMON, Ames Laboratory, Iowa State University, Ames, Iowa 50011, USA — An electron spin in a quantum dot is a promising system for applications in coherent spintronics and quantum computation, but the interaction with the nuclear spins leads to fast decoherence. Subjecting the electron spin to a suitable pulsed control field decouples it from the nuclear spin bath and suppresses decoherence. We study numerically and analytically several most promising decoupling protocols, taking into account the intra-bath coupling, using fully quantum mechanical treatment of the system plus bath dynamics. We show that some high-level protocols extend the coherence time by 3 orders of magnitude for an arbitrary initial spin state. Moreover, we present the protocols which preserve a known initial state with near-to-optimal fidelity for arbitrarily long times.

10:00AM X33.00009 Entanglement entropy of bilinear fermionic systems. LETIAN DING, NOAH Bray-Ali, STEPHAN HAAS, Department of Physics and Astronomy, University of Southern California — We work out a bound of the block entropy $S_k$ for systems of spinless fermions with generic, bilinear interactions. Experimentally relevant examples include p-wave superconductors and cold atom gases near a Feshbach resonance. We find that the block entropy does not obey an area law $S_k \sim c L^{d-1}$ law whenever the system has a $d-1$ dimensional surface of gapless excitations. For other systems, such as a p-wave superconductor with Fermi points, the block entropy does obey the area law, but with a coefficient that diverges as the gap closes.

10:12AM X33.00010 Adiabatic Preparation of Topological Order. ALIOSCIA HAMMA, DANIEL LIDAR, University of Southern California — Topological order characterizes those phases of matter that defy the standard description in terms of symmetry breaking and local order parameters. Topological order is found in nature in the fractional quantum Hall effect. Topologically ordered systems have ground state degeneracy that is robust against perturbations, which has given the root to topological quantum information processing. We discuss the second order quantum phase transition between a spin-polarized phase and a topologically ordered string-net condensed phase. Next we show how to prepare the topologically ordered phase through adiabatic evolution in a time that is upper bounded by $O(\sqrt{n})$. This provides a physically plausible method for constructing a topological quantum memory. We discuss applications to topological and adiabatic quantum computing.

10:24AM X33.00011 Quantum phase transition from magnetic to topological order. ALIOSCIA HAMMA, WEN ZHANG, STEPHAN HAAS, DANIEL LIDAR, University of Southern California — We present a numerical study of the quantum phase transition from the magnetically ordered phase to the topologically ordered phase of a $n$-spins 1/2 system. We show that the derivative of von Neumann entropy of a plaquette diverges at the critical point, signaling a second order quantum phase transition. Moreover, we compute the finite-size scaling of the Topological Entropy, showing how this quantity detects the passage to the topologically ordered phase.

10:36AM X33.00012 Replacing energy by von Neumann entropy in quantum phase transitions. XUN JIA, ANGELA KOPP, Sudip Chakravarty, UCLA — In the thermodynamic limit two distinct states of matter cannot be analytic continuations of each other. Classical phase transitions are characterized by non-analyticities of the free energy. For quantum phase transitions the ground state energy often assumes the role of the free energy. But in a number of important cases this criterion fails, such as the three-dimensional metal-insulator transition of a Fermi liquid. For other systems, such as a p-wave superconductor with Fermi points, the block entropy does obey the area law, but with a coefficient that diverges as the gap closes.

10:48AM X33.00013 Statistical quantum mechanics and entanglement in anisotropic Heisenberg model. YOU-LING CHIANG, Department of Physics, Chinese Culture University, ARMEN KOCHARIAN, Department of Physics and Astronomy, California State University, CHEE YANG, Department of Physics, Tamkang University — The single site quantum and thermal entanglement, concurrences, quantum phase transitions and corresponding quantum critical points are studied in small spin $s = \frac{1}{2}$ and 1 in ferromagnetic and antiferromagnetic Heisenberg dimers. The grand canonical ensemble of Heisenberg clusters is also used for exact calculations of thermal properties, quantum and thermal entanglements of the various spin and fermionic lattice models in the presence of magnetic field. We study the magnetic phase transitions and crossovers driven by external field and temperature. The comparison with the exact solution for Heisenberg model in thermodynamic limit for the limiting cases is also provided. The small Ising, Heisenberg and Hubbard clusters are also used for comparison with the exact Bethe ansatz solutions and predictions of traditional mean field theory and developed perturbation theory about generalization self-consistent solution.

Friday, March 9, 2007 11:15AM - 1:51PM — Session Y32 DAMOP: Mott Phases and Novel Quantum Systems Colorado Convention Center 402

11:15AM Y32.00001 Mott phases and superfluid-insulator transition of spin-3 bosonic atoms in an optical lattice. JEAN-SEBASTIEN BERNIER, University of Toronto, KRISHNENDU SENGUPTA, Saha Institute of Nuclear Physics, YONG BAEK KIM, University of Toronto — We present a theoretical study of the Mott phases and superfluid-insulator transition of spin-3 bosonic atoms with dipolar interactions in an optical lattice. We present the various broken symmetry states obtained and discuss the application of our results to Chromium atoms in optical traps.

11:27AM Y32.00002 Criterion for bosonic superfluidity in an optical lattice. ROBERT DIENER, QI ZHOU, HUI ZHAI, TIN-LUN (JASON) HO, Department of Physics, The Ohio State University — We show that the current method of determining superfluidity in optical lattices based on a visibly “sharp” bosonic momentum distribution $n(k)$ can be misleading, for even a normal Bose gas can have a similarly “sharp” $n(k)$. We show that superfluidity can be detected from the so-called “visibility” $v$ of $n(k)$ — that $v$ must be 1 within $O(N^{-2/3})$, where $N$ is the number of bosons. Many current experiments, however, have interpreted states with $v < 1$ as superfluid. Such states are in fact normal, reflecting strong temperature effects in the system. These normal states, however, allow one to explore the physics in the quantum critical regime.
11:39 AM Y32.00003 Theory of Clock-Shift Density-Profile Measurements and Applications.
KADEN HAZZARD, ERICH MUELLER, Cornell University — “Clock shifts” — shifts in spectroscopic line energies proportional to the local density — provide a spectroscopic way of measuring spatial density profiles. By measuring the absorption of a probe laser at various frequencies, one can obtain a histogram of the number of particles with the associated local densities. Campbell et al. (Science 313, 649 (2006)) have recently imaged the “wedding-cake structure” of the Mott insulator phase in trapped ultracold bosons in optical lattices, using this technique. We develop a theory of clock-shifts for these systems, making comparisons with experiment. We find qualitative agreement with experiment using the simplest strong-coupling mean-field theory with a local density approximation, and a harmonic, isotropic trap model. We show which embellishments to these approximations are best at accounting for the experimental data. We propose applications of this technique to cooling, thermometry, and measurement of correlations, giving an elementary theory of each. Finally, we highlight a superfluid shell structure that can be particularly apparent in these experiments.

11:51 AM Y32.00004 Synchronization versus dephasing in the pairing dynamics of cold fermions, ROMAN BARANKOV, University of Illinois at Urbana-Champaign, LEONID LEVITOV, Massachusetts Institute of Technology — Motivated by recent experiments on degenerate Fermi gases with time-dependent interaction [1,2], we consider the time dynamics of BCS-paired fermions with switchable interaction. Several new regimes [3] of dissipationless coupled dynamics of the collective BCS mode and individual fermion pair states are identified and explored. The system can exhibit synchronized evolution in which all pair states are fully phase-locked, transforming to a Landau-damped dephased behavior upon variation of coupling strength. At the synchronization-dephasing transition the amplitude of long-time persistent oscillations vanishes. A second transition is found in the dephased regime, at which the long-time asymptotic constant value of pairing amplitude vanishes. Using a combination of numerical and analytical methods we establish a continuous (type II) character of both transitions. We also propose an experiment which could probe these new dynamical states.


12:03 PM Y32.00005 Quantum phase transitions of polar molecules in bilayer systems.
DAW-WEI WANG, National Tsing-Hua University — We investigate the quantum phase transitions of bosonic polar molecules in a two-dimensional double layer system. We show that an interlayer bound state of dipoles (dimers) can be formed when the dipole strength is above a critical value, leading to a zero energy resonance in the interlayer s-wave scattering channel. In the positive detuning side of the resonance, the strong repulsive interlayer pseudo-potential can drive the system into a maximally entangled state, where the wavefunction is a superposition of two states that have all molecules in one of the two layers and none in the other. We critically discuss how the zero-energy resonance, dimer states and the maximally entangled state can be measured in time-of-flight experiments.

12:15 PM Y32.00006 Quantum phase diagram of Polar Molecules in 1D Double Wire Systems.
CHI-MING CHANG, DAW-WEI WANG, National Tsing-Hua University — We study the quantum phase transitions of fermionic polar molecules loaded in a double wire potential. By tuning the magnitude and direction of external electric field we observed many interesting quantum phases in different parameter range, including an easy-plane spin density wave, a triplet superconducting phase, and a truly long range order of easy-axis ferromagnetic phase in strong interacting regime. We also discuss how these exotic quantum phases can be measured in the existing experimental techniques.

12:27 PM Y32.00007 Hidden order in one dimensional Bose insulators, EMANUELE DALLA TORRE, Department of Condensed Matter Physics, The Weizmann Institute of Science, EREZ BERG, Department of Physics, Stanford University, EHUD ALTMAN, Department of Condensed Matter Physics, The Weizmann Institute of Science — We investigate the phase diagram of spinless bosons with long range (\(\propto 1/r^3\)) repulsive interactions, relevant to ultracold polarized atoms or molecules, using DMRG. Between the two conventional insulating phases, the Mott and density wave phases, we find a new phase possessing hidden order revealed by non local string correlations analogous to those characterizing the Haldane gapped phase of integer spin chains. We develop a mean field theory that describes the low energy excitations in all three insulating phases. This is used to calculate the absorption spectrum due to oscillatory lattice modulation. We predict a sharp resonance in the spectrum due to a collective excitation of the new phase that would provide clear evidence for the existence of this phase.

12:39 PM Y32.00008 Phase-locking transition of coupled low-dimensional superfluids, LUDWIG MATHEY, Harvard University, ANATOLI POLQOVNIKOV, ANTONIO CASTRO NETO, Boston University — We study the phase-locking transition of two coupled low-dimensional superfluids, either two-dimensional superfluids at finite temperature, or one-dimensional superfluids at zero temperature. We find that these superfluids have a strong tendency to phase-lock. The phase-locking is accompanied by a sizeable increase of the transition temperature (\(T_c / T_K\) in 2D) of the resulting double-layer superfluid, which suggests a plausible way of observing the Kibble-Zurek mechanism in two-dimensional cold atom systems by rapidly changing the ratio \(T_c / T_K\) varying the tunneling rate between the superfluids. When the two superfluids interact with each other, which is the case for polar condensates or for radio frequency induced double well potentials, further phases can be realized. We also extend the discussion to more than two coupled superfluids.

12:51 PM Y32.00009 Quantum quenches in a spinor condensate, AUSTEN LAMACRAFT, University of Oxford — We discuss the ordering of a spin-1 condensate when quenched from its paramagnetic phase to its ferromagnetic phase by reducing magnetic field. We first elucidate the nature of the equilibrium quantum phase transition, which has a multicritical point when the magnetization in the direction of the field vanishes. Quenching rapidly through this transition reveals XY ordering either at a specific wavevector, or the ‘light-cone’ correlations familiar from relativistic theories, depending on the endpoint of the quench. For a quench proceeding at a finite rate the ordering scale is governed by the Kibble-Zurek mechanism. The creation of vortices through growth of the magnetization fluctuations is also discussed. The long time dynamics again depends on the endpoint, conserving the order parameter in zero field, but not at finite field, with differing exponents for the coarsening of magnetic order. The results are discussed in the light of a recent experiment by Sadler et al.

1:03 PM Y32.00010 Absorption of microwave radiation by an array of vortices in a p-wave superfluid of fermionic cold atoms, EYTAN GROSFELD, NIGEL COOPER, ADY STERN, RONI ILAN, Weizmann Institute of Science — We propose an experiment to identify the weak-pairing (“non-abelian”) phase of a two-dimensional p-wave superfluid of cold atoms by microwave absorption. We consider transitions between two atomic hyperfine states, where atoms in the ground state form a rotated p-wave superfluid, and atoms in the excited state are subject to a rotation and a periodic potential. We focus our calculations on absorption originating from zero energy Majorana states present in cores of vortices of the weakly paired superfluid, and identify van-Hove type singularities in the absorption spectrum. The absorption peaks are unique to the weak-pairing phase and their appearance in the spectrum can be translated to the weak-pairing phase. We discuss how these results can be extended to three dimensional superfluids, and explore extensions of non-abelian statistics to multiple two-dimensional layers.
1:15PM Y32.00011 Time-dependent electromagnetic wave dynamics in ultracold, high-density Rb vapor, M. D. HAVEY, S. BALIK, C. I. SUKENIK, Old Dominion University, D. V. KUPIRANOV, I. M. SOKOLOV, St. Petersburg State Polytechnic University — Recent experiments and theoretical results on light localization in condensed samples show that diffusive transport is strongly suppressed and that a regime of anomalous diffusion develops dynamically. Proximity of the light localization threshold can be detected through time evolution of either forward or diffusely scattered light. We report in this paper experimental and theoretical results on time-dependent light scattering in the spectral vicinity of the F = 2 - F’ = 3, and the F = 1 - F’ = 0 optical transitions in dense, ultracold atomic 87Rb samples formed in an optical dipole trap.

1Supported by NSF

1:27PM Y32.00012 Correlated Wavefunction for the Li Atom, FRANK HARRIS, QTP, U. of Florida and Dept. of Physics, U. of Utah — Accurate wavefunctions are extremely valuable as tools for gaining understanding of quantum systems. Here we use a wavefunction explicitly containing all the interparticle distances to obtain a highly precise description of the ground state of the Li atom. In contrast to the widely used Hylleraas approach (in which the interelectron distances enter the wavefunction only as integer powers), our wavefunction exhibits an exponential dependence on all the interparticle distances, with a spatial dependence (before imposing spin and symmetry restrictions) of the form \[ \sum_{n=1}^{N} c_n \exp(-w_1 r_1 - w_2 r_2 - w_3 r_3 - u_1 r_{12} - u_2 r_{13} - u_3 r_{23}), \] where \( r_i \) are electron-nuclear distances, \( r_{ij} \) are electron-electron distances, and \( w_i \) and \( u_i \) are parameters. When the nonlinear parameters are carefully optimized (a nontrivial task), this type of basis causes a far more rapid convergence (with \( N \)) than the Hylleraas basis. We will survey the results we have obtained and compare with other studies of the Li atom.

1Supported by U.S. NSF Grants PHY-0601758 and DMR-0325553

1:39PM Y32.00013 Diabolic Topology, Berry Phase and Optical Phase Shifts of Light in Mobius-Type Strips, RADHA BALAKRISHNAN, The Institute of Mathematical Sciences, India, INDUBALA SATIJA, George Mason University — We compute the optical phase shifts between the left and the right-circularly polarized light after it traverses non-planar cyclic loops describing the boundary curves of twisted strips. These optical results expressed in quantum-mechanical language in fact illustrate the phenomenon of Berry phase. Equation for the evolution of the fields described by Fermi-Walker formulation is mapped to Schroedinger equation with Hamiltonian whose eigenvalues are equal to the \( \pm \kappa \) where \( \kappa \) is the curvature of the path. The inflexion points underlying the twisted strips manifest as the diabolic crossings of the quantum Hamiltonian. For the Mobius loops, the critical width where the diabolic geometry resides also correspond to the characteristic width where the optical phase shift is minimal.