43rd Annual Meeting of the APS Division of Atomic, Molecular and Optical Physics
Orange County, California
http://www.aps.org/meetings/meeting.cfm?name=DAMOP12
Monday, June 4, 2012 6:00PM - 8:00PM –
Session 1A Welcome Reception Poolside

6:00PM 1A.00001 WELCOME RECEPTION –

Tuesday, June 5, 2012 8:00AM - 9:30AM –
Session A1 Prize Session Grand Ballroom A-D - Chair: Gerald Gabrielse, Harvard University

8:00AM A1.00001 Davisson-Germer Prize in Atomic or Surface Physics Lecture: Exploring Flatland with Cold Atoms JEAN DALIBARD, CNRS and ENS — A two-dimensional Bose fluid is a remarkably rich many-body system, which allows one to revisit several features of quantum statistical physics. Firstly, the role of thermal fluctuations is enhanced compared to the 3D case, which destroys the ordered state associated with Bose-Einstein condensation. However interactions between particles can still cause a superfluid transition, thanks to the Berezinskii-Kosterlitz-Thouless mechanism. Secondly, a weakly interacting Bose fluid in 2D must be scale-invariant, a remarkable feature that manifests itself in the very simple form taken by the equation of state of the fluid. In this talk I will present recent experimental progress in the investigation of 2D atomic gases, which provide a nice illustration of the main features of low dimensional many-body physics.

8:30AM A1.00002 Prize for a Faculty Member for Research in an Undergraduate Institution Lecture: Research (Teaching) with Bose-Einstein Condensates1. DAVID HALL, Amherst College — Bose-Einstein condensation in dilute gases, with its myriad ramifications in fields as diverse as atomic, condensed-matter, cosmological, fluid, quantum, and statistical physics, offers unique possibilities for the synthesis of research and pedagogy. The highly visual nature of the experiments can make Bose-Einstein condensates a particularly compelling teaching instrument, particularly for those encountering these topics for the first time. The associated technological challenges provide copious opportunities for development of fundamental research skills while retaining the intimate context of tabletop research. Our program at Amherst College pursues studies of multicomponent condensates, tunable ultracold collisions (i.e., Feshbach resonances), and topological defects (e.g., vortices). In this talk I will describe our experimental efforts in these three principal directions, taken singly and in combination, with a nod to the peculiarities and opportunities inherent to an essentially undergraduate research program.

1Supported by the Research Corporation and the National Science Foundation.

9:00AM A1.00003 Will Allis Prize for the Study of Ionized Gases Lecture: Electron and Photon Collisions with Atoms and Molecules, PHILIP G. BURKE, Queen’s University Belfast — After a brief historical introduction this talk will review the broad range of collision processes involving electron and photon collisions with atoms and molecules that are now being considered. Their application in the analysis of astronomical spectra, atmospheric observations and laboratory plasmas will be considered. The talk will review the R-matrix computational method which has been widely used by international collaborations and by other scientists in the field to obtain accurate scattering amplitudes and cross sections of importance in these applications. Results of some recent calculations of electron and photon collisions with atoms and molecules will be presented. In conclusion some challenges for future research will be briefly discussed.

Tuesday, June 5, 2012 10:30AM - 12:30PM –
Session B1 Invited Session: Synthetic Gauge Fields in Quantum Gases Congjun Wu, University of California, San Diego

10:30AM B1.00001 Light induced gauge fields and spin orbital coupling in cold atomic gas1 . IAN SPIELMAN, JQI, NIST and the University of Maryland — Here I present our experimental work synthesizing gauge fields for Bose-Einstein condensates (BECs). I will first summarize our earlier work creating a scalar (abelian) gauge field (akin to the electromagnetic vector potential) and then focus in detail our current work creating a matrix valued (although still abelian) gauge field. I will discuss this gauge field in the language of spin-orbit coupling where it consists of an equal sum of Rashba and Dresselhaus couplings. Specifically, we couple two internal states of rubidium 87 with a pair of “Raman” lasers and load our BEC into the resulting adiabatic eigenstates. In agreement with theory, we observe that below a critical coupling strength our BEC has well defined spin degrees of freedom and acts like a spin-orbit-coupled spin-1/2 Bose gas. As a function of the Raman laser strength, a new exchange-driven interaction between the two dressed spins develops, which drives a (quantum) phase transition from a state where the two dressed spin states spatially mix, to one where they phase separate. Our 3D mean field theory accurately locates the critical laser strength for this transition. Going beyond this simple modification to the spin-dependent interaction, we show that in the limit of large laser intensity, the particles act as free atoms, but interact with contributions from higher even partial waves.

1This work was partially supported by ONR; ARO with funds from both the DARPA OLE and the Atomtronics MURI; and the NSF through the Physics Frontier Center at JQI.

11:00AM B1.00002 Experimental realization of spin-orbit coupling in degenerate Fermi gas. JING ZHANG, Shannxi University, Taiyuan 030008, P.R. China — We report the first experimental realization of SO coupled degenerate Fermi gas. Evidences of spin-orbit coupling have been obtained from the Raman Rabi oscillation and the spin-dependent momentum distribution asymmetry. We also find that the momentum distribution in helical bases is consistent with topological changes of Fermi surfaces. In the near future, we plan to bring the system close to a Feshbach resonance where the s-wave interaction become strongly attractive. This progress enables us to study stronger pairing and higher Tc enhanced by SO coupling in resonant interacting Fermi gases and topological insulator and topological superfluid in a more flexible setup in near future.
11:30AM B1.00003 Topological quantum criticality in spin-orbit coupled fermions$^1$, SUMANTA TEWARI, Physics and Astronomy, Clemson University, Clemson, SC 29634 — Spin-orbit coupled fermions offer a fascinating playground for realizing interesting topological quantum phases and the associated quantum critical phenomena. In two dimensions and in the presence of an attractive s-wave pairing interaction and a Zeeman field, spin-orbit coupled fermions can condense into a fully gapped non-Abelian topological superfluid phase separated from a conventional s-wave superfluid phase by a topological quantum phase transition. The critical point for this transition is marked by the proliferation of gapless nodal quasiparticles which can be tracked by studying the momentum-resolved excitation spectrum from the center of the Brillouin zone. In three dimensions the same system goes through a series of topological quantum transitions with increasing Zeeman field and the low energy excitations in some of these phases realize the long-sought low-temperature analog of Weyl fermions of particle physics. In this talk I will describe in some detail the interesting topological phases and the associated quantum criticality that can be realized using spin-orbit coupled fermions in cold atom systems.

$^1$Work done at Clemson University, Washington State University, Pullman, and CMTC, UMD. Work supported by DARPA MTO, DARPA QuEst, and JQI-NSF-PFC

12:00PM B1.00004 Spin-Orbit Coupled Quantum Gases, HUI ZHAI, Institute for Advanced Study, Tsinghua University — In this talk I will discuss both spin-orbit coupled Bose condensate and degenerate Fermi gases. In the first part of this talk, I will discuss bosons with Rashba type spin-orbit coupling. We find the ground state exhibits two distinct non-trivial phases: the plane wave phase and the stripe superfluid phase. And the finite temperature thermal fluctuations can lead to an even more interesting boson paired superfluid state with half vortices. I will further discuss collective mode of spin-orbit coupled condensate. We find the dipole modes of a BEC is no longer harmonic due to the non-abelian nature of the gauge potential, and there will be a magnetization oscillation synchronized to the dipole motion due to the absence of Galilean invariance. Macroscopic quantum tunneling will also take place during the dipole oscillation. In the second part of this talk, I will discuss degenerate Fermi gases and the BEC-BCS crossover with spin-orbit coupling. I will talk about spin dephasing and interaction effects in the Raman induced spin dynamics, and the topological change of Fermi surfaces. I will emphasize that Rashba spin-orbit coupling can significantly enhance the pairing strength and the superfluid transition temperature.

Tuesday, June 5, 2012 10:30AM - 12:06PM — Session B2 Atomic Spin Dynamics Grand Ballroom GF - Chair: Chandra Raman, Georgia Tech

10:30AM B2.00001 Spin instabilities in an ultra-cold gas, JEFFREY MCGUIRK, DORNA NIROOMAND, LYDIA ZAJICZEK, Simon Fraser University — We study spin dynamics and instabilities in an out-of-equilibrium quantum gas. Using an optical technique, we imprint arbitrary one-dimensional spin structures in a trapped gas of $^{87}$Rb atoms near quantum degeneracy. These spin structures can exhibit instabilities, such as the Caustic instability, in which a strong longitudinal spin gradient is unstable to transverse perturbations. This instability can lead to large-amplitude spontaneous transverse magnetization oscillations. We report on progress towards driving and observing these instabilities.

10:42AM B2.00002 Spatial modulation of immiscible $^{87}$Rb hyperfine states$^1$, DANIEL CAMPBELL, RYAN PRICE, SUBHADEEP DE, University of Maryland, JQI, IAN SPIELMAN, NIST and University of Maryland, JQI — Using adiabatic rapid passage in the presence of RF dressing, atoms are transferred to an eigenstate with equal $m_f = -1$ and $m_f = +1$ components in the $F = 1$ ground state manifold of $^{87}$Rb. There exists a critical coupling where the spin mixing term of the RF dressing competes with the energy gain of spin ordering due to the spin dependent interaction term. We investigate the relationship between the number of spin domains and the quench of RF dressing.

$^1$NSF through PFC at JQI, and ARO with funds from both Atomtronics MURI and DARPA OLE

10:54AM B2.00003 Non-equilibrium Spin Domains in Quenched Sodium Spinor Bose-Einstein condensates$^1$, ANSHUMAN VINIT, EVA BOOKJANS, CHANDRA RAMAN, Georgia Institute of Technology — We report spontaneous spin domain formation in sodium Bose-Einstein condensates that are quenched, i.e. rapidly tuned, through a quantum phase transition from polar to antiferromagnetic phases. A microwave “dressing” field globally shifts the energy of the $m_F = 0$ level below the average of the $m_F = \pm 1$ energy levels, inducing a dynamical instability recently uncovered by our group [1]. We use local spin measurements to quantify the spatial ordering kinetics in the vicinity of the phase transition. For an elongated BEC, the instability nucleates small antiferromagnetic domains near the center of the polar condensate that grow in time along one spatial dimension. After a rapid nucleation and coarsening phase, the system exhibits long timescale non-equilibrium dynamics without relaxing to a uniform antiferromagnetic phase. We investigate the relationship between the number of spin domains and the quench of RF dressing.


$^1$This work was supported through funds from the DoE AMOS program and the DARPA QuASAR program through a grant from AFOSR.

11:06AM B2.00004 Dynamics of multi-component fermions in optical lattices, CHRISTOPH BECKER, JASPER SIMON KRAUSER, JANNE HEINZE, NICK FLÄSCHNER, Sören Götzte, KLAUS SENGSTOCK, Institute for Laser Physics, Luruper Chaussee 87, 22521 Hamburg, Germany, BFM TEAM — Quantum gases in optical lattices offer intriguing possibilities for quantum simulation due to the full control over lattice and interaction parameters as well as the internal atomic degrees of freedom. In our setup, we produce different interacting spin-mixtures of fermionic K atoms and load them into an optical lattice. The atoms behave similar to electrons in a crystal. However, in contrast to spin-1/2 electrons, potassium possesses high spin, which has important effects on the properties of the system. We induce dynamics by quenching the system from a polarized to a non-polarized regime and compare our experimental data to theoretical calculations. In the latter, we assume a simplified two-particle model which is in very good agreement with our observations. Extending the calculations to larger many-body system may guide the experiment to study complex fermionic lattice-systems beyond conventional spin-1/2 systems.

11:18AM B2.00005 Properties of excited states of a one-dimensional gas of spin-1 Bose atoms in a magnetic field, VLADIMIR YUROVSKY, School of Chemistry, Tel Aviv University — Zeeman shifts of atom energies in an inhomogeneous magnetic field depend on the spin and coordinate states of the atoms. This dependence lifts the integrability of a Yang — Gaudin one-dimensional spinor gas with zero-range interactions. Eigenstates of such a gas of Bose atoms with two spin states are analyzed here using symmetric group representations. The system has three integrable points: the ideal and Tonks-Gerardeau gases at zero and infinitely-strong interatomic interactions, respectively, and the Yang solution at the zero magnetic field (see, e.g., [1]). Approximate eigenenergies and eigenfunctions are evaluated in the vicinity of each of the integrable points. Applicability ranges of corresponding approximations are estimated in dependence of the number of atoms.

11:30AM B2.00006 Matter-wave amplification in a seeded $^{23}$Na spinor Bose-Einstein condensate. JONATHAN WRUBEL, HYEWON PECHKIS, Joint Quantum Institute, NIST and the University of Maryland, PAUL GRIFFIN, University of Strathclyde, RYAN BARNETT, ELLE TIESINGA, PAUL LETT, Joint Quantum Institute, NIST and the University of Maryland — In an $F = 1$ spinor condensate, spin-changing interactions of atoms in the $|m_F, m_{Fz}| = |0, 0\rangle$ state can only produce the $|0, 0\rangle$ (unchanged) or $|1, -1\rangle$ states. Because of the ideally perfect correlation in the production of $m_F = -1$ and $m_F = +1$ atoms, the magnetization $m = n_{m_F = 1} - n_{m_F = -1}$ is a squeezed quadrature of the system. Here we use a microwave-dressed $^{23}$Na Bose-Einstein condensate to create a nonlinear matter-wave amplifier which can produce spin-squeezed states. We then use microwaves to transfer a fraction of the $m_F = 0$ condensate into a coherent seed of $m_F = +1$ atoms. After some evolution time, we show that $n_{m_F = 1}$ can be used as a large amplitude measurement of only a few atoms initially in the $m_F = -1$ state. This kind of measurement may be important in achieving high phase sensitivity in Heisenberg-limited matter-wave interferometers.

11:42AM B2.00007 Manipulating dipolar and spin-exchange interactions in spin-1 Bose-Einstein condensates$^1$. BO-YUAN NING, Department of Optical Science and Engineering, Fudan University, Shanghai 200433, China, S. YI, Institute of Theoretical Physics, Chinese Academy of Sciences, Beijing 100190, China, JUN ZHUANG, Department of Optical Science and Engineering, Fudan University, Shanghai 200433, China, Q. J. YOU, Department of Physics, Fudan University, Shanghai 200433, China, WENXIAN ZHANG, Department of Optical Science and Engineering, Fudan University, Shanghai 200433, China — For a spin-1 Bose-Einstein condensate (BEC), it has been a challenge to experimentally single out the effects of the magnetic dipolar and the spin-exchange interactions, which are usually entangled together and cooperatively determine the spin dynamics. In this work, we develop a generalized WAHUHA rf pulse sequence to suppress dipolar interaction and employ the periodic dynamical decoupling optical pulse sequence to suppress the spin-exchange interaction through Freshbach resonance, respectively. Our results demonstrate that the two sequences are independent of each other and suppress substantially the spin interaction. With this scheme, it is possible to make one spin interaction overwhelm the other and dominate the spin dynamics, so that one can investigate unambiguously the effects of the corresponding spin interaction. Moreover, the two sequences can be applied together to freeze the spin dynamics, which provides an opportunity to manufacture more sensitive magnetometers based on spin-1 BECs. Our method is easy to implement in experiments and is useful to investigate individually the effects of each spin interaction in spinor BECs.

$^1$NFSC, NCET, Shanghai Pujiang Program

11:54AM B2.00008 Quantum Spin Dynamics in Spin-1 BEC$^1$. COREY GERVING, THAI HOANG, BEN LAND, MARTIN ANQUEZ, CHRIS HAMLEY, MICHAEL CHAPMAN, Georgia Institute of Technology — Current study in quantum dynamical evolution of complex systems investigates quantum many-body systems characterized by fluctuations and quantum correlations. Advances in cold atom physics have provided new tools for exploring important topics in this area including atomic squeezed states and non-equilibrium dynamics of many-body quantum systems. Here, we study quantum spin dynamics of a spin-1 condensate.

Tuesday, June 5, 2012 10:30AM - 12:30PM —
Session B3 Invited Session: Atomic and Molecular Astrophysics

10:30AM B3.00001 Observing the chemical signatures of the oldest, most metal-poor stars$^1$, ANNA FREBEL, Massachusetts Institute of Technology — In their atmospheres, oldest, most metal-poor Galactic stars retain detailed information about the chemical composition of the interstellar medium at the time of their birth shortly after the Big Bang. Extracting such stellar abundances enables us to reconstruct the onset of the chemical evolution. About 5% of metal-poor stars display in their spectrum a strong enhancement of neutron-capture elements associated with the rapid $(r)$ nucleosynthesis process that is responsible for the production of the heaviest elements in the Universe. This forlorn provides a unique opportunity of bringing together astrophysics, nuclear physics and laboratory astrophysics because these objects act as “cosmic lab” for these fields of study. In order to carry out the spectroscopic chemical abundance analyses of these and other stars, atomic data is required for each absorption line to be measured in the spectrum. Only then abundances can be derived. This is of particular importance in those ‘r-process’ stars: Among many other elements, we find the long-lived radioactive isotopes $^{232}$Th (half-life 14 Gyr) and $^{238}$U (4.5 Gyr) in some of these rare objects. Their abundances, in combination with measured in the spectrum. Only then abundances can be derived. This is of particular importance in those ‘r-process’ stars: Among many other elements, we find the long-lived radioactive isotopes $^{232}$Th (half-life 14 Gyr) and $^{238}$U (4.5 Gyr) in some of these rare objects. Their abundances, in combination with.

11:00AM B3.00002 Atomic Data and the Modeling of Supernova Spectra$^1$. CHRISTOPHER FONTES, Los Alamos National Laboratory — The modeling of supernovae (SNe) incorporates a variety of disciplines, including hydrodynamics, radiation transport, nuclear physics and atomic physics. These efforts require numerical simulation of the final stages of a star’s life, the supernova explosion phase, and the radiation that is subsequently emitted by the supernova remnant, which can occur over a time span of tens of thousands of years. While there are several different types of SNe, they all emit radiation in some form. The measurement and interpretation of these spectra provide important information about the structure of the exploding star and the supernova engine. In this talk, the role of atomic data is highlighted as it pertains to the modeling of supernova spectra. Recent applications involve the Los Alamos OPAL opacity database, which has been used to provide atomic opacities for modeling supernova plasmas under local thermodynamic equilibrium (LTE) conditions. Ongoing work includes the application of atomic data generated by the Los Alamos suite of atomic physics codes under more complicated, non-LTE conditions [3]. As a specific, recent example, a portion of the x-ray spectrum produced by Tycho’s supernova remnant (SN 1572) will be discussed [4].


$^1$This work was performed under the auspices of the U.S. Department of Energy by Los Alamos National Laboratory under Contract No. DE-AC52-06NA25396.

11:30AM B3.00003 The Need for Oscillator Strengths to Study the Molecular Universe$^1$, STEVEN FEDERMAN, University of Toledo — Oscillator strengths, or equivalently absorption cross sections, are needed to convert the amount of absorption seen in spectra into abundances and to determine dissociation rates in photochemical models of astronomical environments. In turn, the measurements provide important information on molecular structure. I will focus on CO, which is observed in planetary atmospheres and comets, in interstellar clouds and disks surrounding newly formed stars, and in gas associated with the late stages of stellar evolution. Its photodissociation involves line absorption, and oscillator strengths are needed for calculating the amount of self shielding, where optically thick absorption drastically lowers the photodissociation rate.

$^1$This research was supported by grants from NASA and STScI.
properties and nature of the solid state as well as the contribution of gas phase lines is important. and strengths of allowed transitions for excitation, and chemical formation and destruction rates for local chemistry. Even for understanding the continuum the spectroscopy spanning 3 to 680 microns poses an enormous challenge to astronomers, modelers, databases and laboratory astrophysics. Large differences in

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Data Required

俊约翰，美国航天局喷气推进实验室，加利福尼亚理工学院—The Herschel Space Observatory and the Stratospheric Observatory for Infrared Astronomy are allowing the far infrared region of the spectrum to be exploited completely for the first time. Interpreting the wealth of new data from these missions which perform photometry in many colors, moderate resolution spectroscopy and high resolution spectroscopy spanning 3 to 680 microns poses an enormous challenge to astronomers, modelers, databases and laboratory astrophysics. Large differences in instrument capability, beam sizes and the regions that can be studied as a function of wavelength place a premium on supporting data for accurate interpretation. The supporting data must include line frequencies, line strengths, transition degeneracy, and energy for assignments and local dynamics, collisional cross sections and strengths of allowed transitions for excitation, and chemical formation and destruction rates for local chemistry. Even for understanding the continuum the properties and nature of the solid state as well as the contribution of gas phase lines is important.

Tuesday, June 5, 2012 10:30AM - 12:30PM –

Session B4 Invited Session: Frontiers of Intense Laser Physics

Garden 1-2 - Chair: Anthony Starace, University of Nebraska

10:30AM B4.00001 Gigavolt-Energy Electrons and Femtosecond-Duration Hard X-Rays Driven by Extreme Light1, DONALD UMSTADTER, University of Nebraska, Lincoln — The interactions of high-peak power laser light focused to extremely high intensities, or "extreme light," is at the core of high-energy laser-driven electron accelerators, and novel laser-synchrotron x-ray light sources. The hallmark of extreme light is its ability to cause the instantaneous electron quiver motion to become relativistic. We discuss recent progress in understanding the physics of extreme light, and the advanced electron and x-ray technologies that it drives. Through the mechanism of relativistic self-guiding, focused light from our 100-TW Diocles laser was propagated in plasma at relativistic intensity for distance of 1 cm [corresponding to over 15 vacuum diffraction (Rayleigh) ranges]. As a result of this extended propagation length, electrons were accelerated by a laser-wakefield to near GeV energy in a well-collimated beam. The electron beam was measured to be tunable over a wide energy range, 100 – 800 MeV, with 5– 25% energy spread, and 1– 4-mrad divergence angle. The experimental results were found to be in reasonable agreement with the results of numerical simulation, which predict even higher electron energy (multi-GeV) with our recently upgraded peak laser power (>0.5 PW). These characteristics, along with their lack of any measurable amount of dark-current, make these electron beams good candidates for driving synchrotron x-ray sources. The development of one such x-ray source will also be discussed, one driven by inverse Compton scattering of laser light by laser-accelerated electrons. Its small radiation source size (~ 10 microns) and low angular beam divergence (< 10 mrad) make it quite promising for applications in radiology. By virtue of its ultra-short pulse duration (< 10 fs) and wide energy tunability (10 keV – 10 MeV), it can also be used to probe matter with atomic-scale spatial and temporal resolution—simultaneously.

1The following funding support is gratefully acknowledged: AFOSR FA9550-08-1-0232 and FA9550-11-1-0157; DOE DE-FG02-05ER15663; and DTRA HDTRA1-11-C-0001.

11:00AM B4.00002 Combined Ion and Laser Field Effects in Intense Laser Ionization of Atoms and Molecules1, ROBERT JONES, University of Virginia — The simplem’s approximation and its extension to the 3-step model have been extremely successful in guiding our understanding of strong field processes in atoms and molecules and the development of applications from molecular imaging through electron rescattering and HHG, to the attosecond streak camera. Even so, the principal approximations, adiabatic tunneling ionization followed by laser driven electron dynamics in a flat ionization continuum are not always applicable. We have been investigating two such problems. The first is near threshold ionization in the presence of a low frequency field. In this case, the field of the parent ion can dramatically influence the momentum and energy transfer to the continuum electron. The second is multi-electron dissociative ionization (MEDI) of small molecules (e.g. N2, O2, CO, NO) in asymmetric fields. It has long been recognized that non-adiabatic electron localization during the dissociation of a molecule in the presence of an intense laser can lead to the production of higher charge states. The use of asymmetric laser fields allows us to test the directionality of the dissociation predicted by the enhanced ionization model and the time-scales over which electron localization may occur.

1Supported by DOE

11:30AM B4.00003 Optics in the Relativistic Regime, TOSHIKI TAJIMA, IZEST — Optics has extended the frontier of low energy physics. Here we present the progress in the opposite direction of relativistic intensity regime of optics. With intense and large energy laser, particles may be accelerated to high energies via laser wakefield acceleration (Tajima and Dawson, 1979) over a compact distance orders of magnitude shorter than the RF approach. We should be able to accelerate electrons (over 30m) and ions (over cm) toward TeV with an existing kJ laser. We can check Lorentz invariance in the ultrarelativistic regime. Further, laser allows us to explore the presence of weakly coupling fields such as Dark Matter and Dark Energy with an unprecedented sensitivity. We call this emerging capability as the Laser Particle Physics Paradigm (LP3).

12:00PM B4.00004 Probing Ultrafast Processes in Intense Laser–Matter Interactions1, S.X. HU, Laboratory for Laser Energetics, University of Rochester — This talk reports on computational studies of using sub-femtosecond/attosecond extreme ultraviolet and soft-x-ray pulses to probe ultrafast processes in intense laser interactions with atoms, molecules, and plasmas. By developing and optimizing the finite-element discrete-variable-representation (FEDVR) combined with the real-space product (RSP) algorithm, a powerful computational method is generated, enabling one to explore transient processes in quantum, few-body systems non-perturbatively driven by strong electromagnetic fields. These studies include attosecond photoelectron microscopy of molecular structures, ultrafast probing ion–atom collisions, as well as exploring electron correlations in single-/double-ionization of helium in intense laser fields. Detailed discussions on what has been learned and what can be done in experiments will be presented. This work was partially supported by the U.S. Department of Energy Office of Inertial Confinement Fusion under Cooperative Agreement No. DE-FC52-08NA28302, the University of Rochester, and the New York State Energy Research and Development Authority. The support of DOE does not constitute an endorsement by DOE of the views expressed in this article. Computational studies conducted utilizing the Roadrunner Supercomputer of the National Institute of Computational Sciences (NICS) at Oak Ridge National Laboratory.

1In collaboration with L. A. Collins, B. Schneider, A. F. Starace, V. N. Goncharov, and S. Skupsky.

Tuesday, June 5, 2012 10:30AM - 12:30PM –

Session B5 Cold Collisions and Ultracold Molecules

Garden 3 - Chair: Phillip Gould, University of Connecticut
10:30AM B5.00001 Travelling wave deceleration of heavy polar molecules in weak-field seeking states, RICHARD HENDRICKS, NICHOLAS BULLEID, SARAH SKOFF, DANIEL SEGAL, BEN SAUER, MICHAEL TARBUSS, EDWARD HIDES, Imperial College, London, SAMUEL MEEK, ANDREAS OSTERWALDER, MAXWELL PARSONS, GABRIELE SANTAMBROGIO, GERARD MEIJER, Fritz-Haber-Institut der Max-Planck-Gesellschaft — Electrostatic forces can be used to decelerate neutral molecules via the Stark interaction. Most Stark decelerators to date use switched dc electric fields to manipulate light molecules in weak field seeking states. More massive molecules have smaller rotational constants and greater kinetic energies at a given velocity, and would require very long decelerators to bring them to rest. We have combined a new cryogenic source of YbF molecules, based on a pulsed solenoid valve cooled to 4K, with a 48cm long travelling wave Stark decelerator that is suitable for decelerating heavy molecules in weak-field seeking states. This decelerator uses continuously modulated sinusoidal electric fields to produce a series of moving 3-dimensional traps that can be continuously slowed to decelerate the molecules within them. We have decelerated YbF molecules from 300m/s to 276m/s. This implies that a 3 metre long decelerator could produce trapped YbF molecules at rest. In a different configuration, our source produces broader pulses of YbF molecules with speeds of 200m/s or less that could be brought to rest with a decelerator that is just 1 metre in length.

10:42AM B5.00002 Continuous Production of Rotational Ground State RbCs via Photoassociation, CHIN BRUZEWICZ, MATTIAS GUSTAVSSON, TOSHIIKO SHIMASAKI, DAVID DEMILLE, Yale University — We photoassociate electronically-excited RbCs molecules into a deeply-bound rotational level of the Ω = 0− component of the (2)ΣI state. For photoassociation on the J = 1 level of the Ω = 0+ component, selection rules from the spontaneous decay constrain the ground state molecules to the J = 0, 2 rotational levels. We are currently investigating methods for the continuous accumulation of rotational ground state RbCs in an optical trap. We also intend to purify the molecular sample by exploiting trap loss due to inelastic scattering, which is predicted to remove only excited RbCs and hence yield a trapped sample of polar ν = J = 0 molecules.

10:54AM B5.00003 Enhanced creation efficiency of polar molecules with a species-selective dipole trap1, BO YAN, BRIAN NEYENHUIS, STEVEN MOSES, JACOB COVEY, DEBORAH JIN, JUN YE, JILLA, NIST, and University of Colorado, Boulder — Quantum degenerate ultracold polar molecules offer the possibility to study many-body physics and exotic phases of matter. In our experiment, we use ultracold fermionic ground-state Krb molecules near quantum degeneracy. A high atom-molecule conversion efficiency at very low temperatures should enable us to create a quantum degenerate dipolar gas. However, the efficiency of molecule creation has two main challenges at very low temperatures. First, the mass and polarizability differences between K and Rb result in a gravitational sag between the two atomic clouds. Second, the differing quantum statistics (bosonic Rb vs. fermionic K) cause a size mismatch between the two clouds when T/T<1 for Rb. To overcome these issues, we have implemented a species-selective dipole trap around 790 nm that has a trapping force on K but not Rb, in addition to the original dipole trap at 1064nm. This new dipole trap allows us to adjust the size and position of the K cloud for optimal spatial overlap with Rb, which can significantly increase the molecule creation efficiency at very low temperatures. This should lead us to a colder, denser gas of ground-state molecules and should allow us to create a degenerate dipolar gas.

1We acknowledge funding from NIST, NSF, AOFORU-MURI, and the NDSEG Graduate Fellowship.

11:06AM B5.00004 Cold Collisions in a K-Rb two species dipole trap, CARLOS MENEGATTI, BRUNO MARANGONI, LUIS MARCASSA, University of Sao Paulo — Several experiments involving cold collisions and cold heteronuclear molecules rely on large and dense atomic samples. In our experiment, we have trapped cold K atoms and Rb atoms in two species crossed broadband optical dipole trap. Our crossed beam configuration uses 25 W of power (at 1064 n, bandwidth of 2 nm) in each beam with about 50 μm waist radius at the focus and a depth of about 700 μK. The dipole trap is loaded from a standard mixed species MOT. In the dipole trap, we have about 2 x 10⁶ K atoms, 7 x 10⁶ Rb atoms, and an average temperature of 20 μK and a density of about 10¹³ atoms/cm³ for both species. We have observed that the K atom population presents an exponential decay with a lifetime of about 200 ms in the absence of Rb atoms. When we add the Rb population in the dipole trap, the K atom population presents a non-exponential decay. We believe that such observation suggests that the mixed sample is photoassociated by the 1064 nm laser, forming an excited state Krb molecule, which further decays forming Krb in the electronic ground state. More results will be discussed during the presentation.

1We acknowledge financial support from FAPESP, CNPq, INCT-IQ.

11:18AM B5.00005 Non-universal binding energies of weakly bound Feshbach molecules1, PAUL JULIENNE, Joint Quantum Institute, NIST and the University of Maryland, JÉRÉMY HUTSON, Durham University, GERHARD ZURN, ANDRE N. WENZ, THOMAS LOMPE, SELIM JOCHIM, Heidelberg University — It is well-known that two atoms weakly bound into a Feshbach molecule have a universal binding energy proportional to 1/α² when the ω-wave scattering length α becomes large compared to a characteristic scale length of the long range potential. Analytic formulas giving the correction to universality in terms of the ratio of α to the scale length for a van der Waals potential have been given by Gribakin and Flambaum [1] and by Gao [2]. We examine the domain of validity of such corrections for several species with different potentials and masses using accurate numerical quantum mechanical calculations for single and coupled channels representations of the interatomic interactions. In particular, we examine Feshbach molecules comprised of two Li fermionic atoms in different spin states. We use new measurements with the two lowest spin states of this species to construct an improved model for very weak binding energies down to a few kHz and consequently obtain a more accurate value of the precise magnetic field at which the s-wave scattering length has its singularity.

1Supported in part by an AFOSR MURI.

11:30AM B5.00006 Resolved-sideband RF spectroscopy on weakly bound Li₂ molecules1, 2, S. JOCHIM, G. ZURN, A.N. WENZ, T. LOMPE, Heidelberg University, Germany, P.S. JULIENNE, JQI/NIST, J.M. HUTSON, Durham University, UK — In a unitary Fermi gas, the scattering length is tuned to infinity, leaving the interacting particle spacing as the only length scale remaining. Recent measurements of the equation of state in an ultracold gas of Li at a Feshbach resonance are so precise that the derivation of universal constants such as the Bertsch parameter is limited by the present knowledge of the resonance position [1]. We have performed RF spectroscopy measurements of the binding energies of weakly bound Li₂ molecules near the broad Feshbach resonance at ∼834 G. To avoid density dependent shifts we start from thermal samples of 30-60 molecules. Resolving sidebands resulting from the quantized relative motion of the dissociated molecules in a cigar-shaped trap with a radial trap frequency of about 349 Hz allows us to measure binding energies with an unprecedented precision of ∼60 Hz. Our results allow for a much more accurate determination of the Feshbach resonance position compared to previous measurements.

1M. Bartenstein et al., PRL 94, 103201 (2005).

2Supported by the Heidelberg Center for Quantum Dynamics and the European Research Council.
11:42AM B5.00007 Towards ultracold RbCa molecules\textsuperscript{1}. MICHAELA KLEINERT, HAYLEY WHITSON, ALEXANDRIA PARSAGIAN, Willamette University — Ultracold heteronuclear molecules have seen increasing interest in the scientific community over the last few years. By controlling their ro-vibrational energy levels, ultracold molecules can be used for high precision spectroscopy, to study cold collisions with rich internal dynamics, as model systems for condensed matter physics, and as qubits in quantum information processing. We study the novel combination RbCa. In addition to a permanent electric dipole moment, it also possesses a permanent magnetic dipole moment. This makes it an ideal candidate to study strong long-range dipole-dipole interactions. We are currently in the process of adding a Ca MOT to our existing Rb MOT and will discuss our current and future efforts toward our goal of creating, for the first time, ultracold RbCa molecules. Molecules, once created, will be detected through resonantly enhanced multi-photon ionization (REMPI). We have also performed ab initio calculations to determine the electronic energy levels of RbCa, and calculated Franck-Condon factors between the ground and several excited states.

\textsuperscript{1}This work has been support by the National Science Foundation, the M.J. Murdock Charitable Trust, and Willamette University.

11:54AM B5.00008 Lifetimes of three particles in an isotropic harmonic trap\textsuperscript{1}. EDMUND MEYER, B.D. ESRY, Department of Physics, Kansas State University — We present an analytic calculation of the energy levels and lifetimes of particles confined by an isotropic harmonic trap. Using a single adiabatic hyperspherical channel, we derive a transcendental equation whose solutions give the energy levels and lifetimes of the trapped states. To obtain a more physical interpretation of the results, we examine two regimes: the oscillator length much greater, and much less than, the two-body s-wave scattering length. For the case of large oscillator length, we find explicit analytical expressions for the lifetime of the trapped states. In particular we find that the lifetime for three identical bosons scales as $|a|^4$, in agreement with previous studies of free-space recombination. Moreover, the decay rate shows resonant enhancements due to Efimov physics just as free space rates do.

\textsuperscript{1}Supported by the National Science Foundation

12:06PM B5.00009 Production of Ultracold Strontium Dimers in Optical Lattices for Precision Measurements and Metrology. CHRISTOPHER OSBORN, GAELE REINAUDI, TANYA ZELEVINSKY, Columbia University — Ultracold diatomic molecules offer exciting possibilities for studies of novel states of matter, quantum information, and precision measurements. We present recent results on the photoassociation of ultracold strontium dimers in optical lattices of various dimensions, including the coherent two-photon production of stable ground state molecules. We discuss features of this two-photon transfer, including the frequencies and strengths of the relevant transitions, and the associated Autler-Townes splitting. Further, we present results on the molecular lifetime, and its dependence on the dimensionality of the lattice. In addition, we highlight further work toward the development of deeply bound (10’s of THz) molecules for use in a molecular clock.

12:18PM B5.00010 Quantum control of ultracold Rb\textsuperscript{1}. SVETLANA MALINOVSKAIA, THOMAS COLLINS, SPENCER HORTON, Stevens Institute of Technology — Ultracold control has originated on the base of latest developments in the field of ultracold gases. Control of electron dynamics within the hyperfine structure in the ultracold Rb atom using chirped pulses aimed to induce the desired excitations and create predetermined non-equilibrium states will be discussed. We show population inversion within the hyperfine levels of $5^2S_{1/2}$ state through Raman transitions by making use of a single ns chirped pulse having $kW/cm^2$ beam intensity. Satisfying the one-photon resonance condition with a hyperfine state of the $5^2P_{1/2}$ or $5^2P_{3/2}$ state allows us to enter the adiabatic region at field intensities such that the corresponding Rabi frequencies are less than or equal to the hyperfine splitting. We will highlight the studies of the impact of decoherence through the process of cooling of internal degrees of freedom in KRB from the Feshbach state by implementation of optical frequency combs in a framework of a semiclassical model.

\textsuperscript{1}This research is partially supported by the National Science Foundation under Grant No. PHY-0855391.

Tuesday, June 5, 2012 10:30AM - 12:30PM – Session B6 GPMFC: Invited Session: The Fine Structure Constant

10:30AM B6.00001 Determination of the fine structure constant from atom interferometry\textsuperscript{1}. Saida Guellati-Kéblifa, Saïda Guellati-Kéblifa, François Nez and François Biraben, Harvard University — We report a new measurement of the atomic recoil velocity using atom interferometry and Bloch oscillations (BO) in a vertical accelerated optical lattice. Such a measurement yields to a determination of $\frac{h}{m_{\text{Rb}}}$ ($m_{\text{Rb}}$ is the mass of Rubidium atom) which can be used to obtain a value of the fine structure constant following the equation:

$$\alpha^2 = \frac{2R_\infty}{c} \frac{m_{\text{Rb}}}{m_e} \frac{h}{m_{\text{Rb}}} \tag{1}$$

where the Rydberg constant $R_\infty$ and the mass ratio $m_{\text{Rb}}/m_e$ are precisely known. The key idea to precisely determine the recoil velocity, is to transfer to the atoms as many recoils as possible and to measure their velocity variation. For this purpose we use an atomic interferometer consisting in two pairs of $\pi/2$ pulses combined with Bloch oscillations. The first pair selects an atomic sub recoil velocity Ramsey pattern from an ultra cold Rb atoms sample. We then accelerate the atoms and give to the selected atoms up to 1000 recoils by means of Bloch oscillations. The final velocity distribution is measured by scanning the frequency of the second pair of $\pi/2$ pulses. Following this scheme, we have performed in 2010 a measurement of $\alpha$ with an uncertainty of $6.6 \times 10^{-10}$. Our final result is:

$$1/\alpha = 137.035 999 037(91).$$

(2)

Using this determination, we obtain a theoretical value of the electron anomaly $\alpha_e = 0.001 159 652 181 73(48)$ which is in agreement with the experimental measurement of Gabrielse ($\alpha_e = 0.001 159 652 180 73(28)$). The comparison of these values provides the most stringent test of the QED. Moreover, the precision is large enough to verify for the first time the muonic and hadronic contributions to this anomaly.

\textsuperscript{1}Work completed by Rym Bouchendira, Pierre Cladé, Saïda Guellati-Kéblifa, François Nez and François Biraben.
11:00 AM B6.00002 Most Precise Determination of the Fine Structure Constant: Electron \( g \) and QED. SHANNON FOGWELL HOOGERHEIDE, Harvard University — Currently, the most accurate determination of the fine structure constant comes from our measurement of the electron magnetic moment in Bohr magnetons, \( g/2 = 1.0015965218073(28) \ [0.28 \text{ ppb}] \). This measurement utilized quantum jump spectroscopy of transitions between the lowest quantum levels of a one-electron quantum cyclotron. The single trapped electron itself served as a precise magnetometer to allow for greater accumulation of quantum-jump line shape statistics. The spontaneous emission rate of the single electron at multiple values of the magnetic field was used to correct for the interaction between the electron and a cylindrical cavity, used to inhibit spontaneous emission by about a factor of 200. This measurement, combined with QED theory and small additional standard model corrections yields \( \alpha^{-1} = 137.03599084(51) \). Improvements to the QED theory, to be reported in this session, will allow us to report a slightly shifted value of the fine structure constant with a slightly reduced uncertainty. A new trap, now in operation, is designed to use cavity-sideband cooling to cool the axial motion of a single electron in a Penning trap to near its quantum ground state. The new apparatus also contains a positron source which should allow a greatly improved comparison of the magnetic moments of the positron and electron as a test of CPT invariance. Additionally, the completely new apparatus is designed to reduce the effect of vibrations and thermal fluctuations.

Progress toward improved measurements of both the electron and positron magnetic moments will be summarized.


11:30 AM B6.00003 A tenth-order QED contribution to the lepton \( g-2 \). MAKIKO NIO, RIKEN — The anomalous magnetic moment of the electron \( e \) has played the central role in testing the validity of quantum electrodynamics (QED) as well as the standard model of the elementary-particle physics. In this talk we report further improvement of the test which is made possible by the newly evaluated tenth-order QED contribution to \( a_e \). Altogether 12672 Feynman diagrams contribute to the tenth-order term. To handle them, we have developed the computer algorithm that generates Fortran programs automatically for individual diagrams. The resulting programs have been numerically evaluated on the supercomputer systems at RIKEN. Our preliminary result of the mass-independent tenth-order term, which is universal for all species of leptons, is \( A_1^{(10)} = 9.1 \pm 0.6 \) in units of \( (\alpha/m_e)^2 \).

As a byproduct, the muon contribution to the tenth order \( a_\mu \) is obtained. It is far smaller than the uncertainty of the mass-independent term. We have also improved the eighth-order term by an intense numerical work. The uncertainty in the mass-independent term \( A_1^{(8)} = -1.9109 \pm 0.0021 \) in units of \( (\alpha/m_e)^2 \) has been reduced by about 2/3. The muon contribution to \( a_\mu \) at the eighth order, \( A_1^{(8)}(m_e/m_\mu) = 0.0009222 \) (66), is newly obtained. The improvement in the QED theory leads to about 10% improvement in the theoretical prediction of \( a_e \) and about 30% improvement in the fine-structure constant \( \alpha \) derived from the measured value of \( a_e \) and the QED theory.

12:00 PM B6.00004 A matter wave clock and new measurement of the fine structure constant. SHAU-YU LAN, University of California, Berkeley — The rest mass of a particle defines its Compton frequency, \( mc^2/h \) and thereby sets a fundamental timescale. However, the Compton frequency of a single, non-interacting particle is too high to be harnessed as a clock (about \( 3 \times 10^{25} \) Hz for a cesium atom) and does not directly give rise to observable effects. Here, we demonstrate a clock that stabilizes a radio-frequency signal to a certain fraction of the Cs Compton frequency, using a Ramsey-Bordé matter-wave interferometer combined with an optical frequency comb. The relative phase accumulated between matter-waves travelling along different paths provides us with an indirect way to access the Compton frequency. The paths are defined by atom-laser interactions, and the frequency comb relates the laser frequency to the clock’s own output. In principle, the experiment could still function even if all other standards of measurement were lost. This demonstrates that a single, massive particle indeed defines a timescale, even in practice. This clock relates mass directly to time, which may find application in a new definition of the kilogram with competitive accuracy, by fixing the Planck constant. Moreover, I will report our recent progress on the measurement of the photon recoil frequency using a pair of conjugate Ramsey-Bordé interferometers with large momentum transfer beam splitters. The sensitivity of the interferometers scale quadratically with the momentum transfers on the beam splitters while the common mode noise can be removed by running two interferometers simultaneously. Such a measurement can be used to obtain a new determination of the fine structure constant.

Tuesday, June 5, 2012 10:30AM - 12:30PM –
Session B7 Invited Session: Quantum Control for Quantum Information Processing
Terrace -
Chair: Ivan Deutsch, University of New Mexico

10:30 AM B7.00001 Quantum feedback experiments with atoms and cavities. JEAN-MICHEL RAIMOND, Université Pierre et Marie Curie — Quantum feedback transposes the usual feedback loop concept into the quantum world. A measurement performed on the system by the sensor is used by a controller to infer the system’s state and to steer it towards the target by the action of the actuator. This scheme has to face a fundamental difficulty, since the measurement changes the system’s state. This back-action makes quantum feedback algorithms more complex than their classical counterparts. We report the first successful operation of a repeated quantum feedback loop [1]. It prepares photon number states (from 0 to 4 photons) on-demand in a superconducting microwave cavity and subsequently reverses the effect of decoherence-induced quantum jumps. The quantum sensors are circular Rydberg atoms, performing a Quantum Non Demolition (QND) measurement of the cavity field. Information they provide is used by the controller (real-time computer) to estimate the field state. The controller determines the amplitude of a coherent displacement leading the cavity closer to the target. This displacement is performed by a microwave source acting as the actuator. Iterations of this loop rapidly drive the cavity towards the prescribed target. When it is reached, the actuator idles. It resumes operation when atomic detections indicate that a photon has been lost, or that a thermal photon has appeared. The feedback compensates for these quantum jumps and rapidly restores the field in the target state. In a variant of the experiment, we use quantum actuators, resonant atoms that feed photons back in the cavity when they get lost. This more efficient scheme allows us to stabilize higher photon numbers. These experiments are a first step towards the use of quantum feedback to protect fragile quantum resources. We also consider an alternative route towards state protection based on reservoir engineering [2].


1. Laboratoire Kastler Brossel, ENS, CNRS, UPMC 24 rue Lhomond, F-75005 Paris France
11:00AM B7.00002 Quantum Control and Tomography in the 16-Dimensional Ground Manifold of Atomic Cesium. POUL JESSEN, Center for Quantum Information and Control, College of Optical Sciences, University of Arizona — The standard paradigm for Quantum Information Science involves a collection of qubits, whereas the physical building blocks of a quantum processor or simulator often have more than two accessible levels. Taking advantage of these higher dimensional Hilbert spaces (qudits) requires the development of good laboratory tools for qudit manipulation and readout. We have successfully implemented a protocol for quantum state-to-state mapping in the 16-dimensional hyperfine ground manifold of individual Cesium atoms, using only DC, rf and microwave magnetic fields to drive the atomic evolution. Our control waveforms (rf and $\mu$W phases versus time) are found by numerical optimization, and designed to compensate for errors in the driving and background magnetic fields. Experimentally we achieve a state-to-state mapping fidelity of better than 99%, averaged over a sample of randomly chosen initial and target states. Preliminary results suggest that unitary transformations can be designed and implemented in a similar manner. To perform quantum state tomography, we drive an ensemble of identically prepared atoms with phase modulated rf and $\mu$W fields while performing a continuous weak measurement of an atomic observable via polarization spectroscopy. The resulting measurement record is numerically inverted to obtain an estimate of the unknown quantum state. We have reconstructed the density matrices for a set of randomly chosen pure test states using algorithms based either on least squares fitting or compressed sensing. The latter is slightly more tolerant of experimental errors and achieves an average fidelity above 90%.

11:30AM B7.00003 Synthetic Quantum Matter under the Microscope. MARKUS GREINER, Harvard University — In this talk I will address properties of a gas of polar bosonic molecules confined within single-, bi-, and multi-layer geometries — the molecular dipole moments are aligned perpendicularly to the layers. The results presented are based on Quantum Monte Carlo simulations. I will discuss phases and phase transitions displayed by such systems — with emphasis on solids and supersolids —, and the experimental exotic states of matter within experimental reach.

12:00PM B7.00004 Quantum simulations of magnetism with large numbers of atomic ion spins. RAJIBUL ISLAM, Joint Quantum Institute and University of Maryland Department of Physics — We report the engineering of the form and range of fully-connected Ising interactions and the observation of interesting spin orders in quantum simulations of magnetism with many trapped ion spins. The interaction between the spins is provided through state-dependent laser forces applied to individual ions in a laser-cooled Coulomb crystal. When such a laser force is applied globally, an effective spin-spin interaction emerges that is mediated through the collective motion of the ions. The sign and range of this effective magnetic interaction can be precisely controlled with the laser and any possible spin correlation function can be measured by imaging the state-dependent fluorescence from the ions. We simulate interesting spin models that possess nontrivial ground states for the investigation of quantum phase transitions, quantum frustration, and the emergence of spin liquid behavior. We speculate on the scaling of this system to more than 25 spins, where classical models are not able to calculate ground states or spin dynamics.

3This work was supported by the DARPA Optical Lattice Emulation Program, the NSF Physics Frontier Center at JQI, and the IARP Multiqubit Quantum Coherent Operations program through ARO contract.

Tuesday, June 5, 2012 2:00PM - 4:00PM –
Session C1 Invited Session: Dipolar Quantum Gases
Grand Ballroom BCD - Chair: Doerte Blume, Washington State University

2:00PM C1.00001 Quantum degenerate Bose and Fermi gases of dysprosium. BENJAMIN LEV, Stanford University — Advances in the quantum manipulation of ultracold atomic gases are opening a new frontier in the quest to better understand strongly correlated matter. By exploiting the long-range and anisotropic character of the dipole-dipole interaction, we hope to create novel forms of soft quantum matter, phases intermediate between canonical states of order and disorder. Our group recently created Bose and Fermi degenerate gases of the most magnetic atom, dysprosium, which should allow investigations of quantum liquid crystals analogous to the electron nematics and smectics thought to exist in, e.g., high $T_c$ cuprate superconductors. We present details of recent experiments that created the first degenerate dipolar Fermi gas as well as the first strongly dipolar BEC in low field.

1We thank AFOSR, NSF, and ARO/MURI for funding.

2:30PM C1.00002 Dipolar Chromium BECs. BRUNO LABURTHE-TOLRA, CNRS — Bose-Einstein condensates (BECs) made of $^{52}$Cr atoms reveal new phenomena, due to the presence of the long-range and anisotropic dipole-dipole interactions (see for example [1]). In this talk, I will describe the effect of dipolar interactions on the properties of multi-component (spinor) Cr condensates at extremely low magnetic fields. Due to its anisotropy, the dipolar interaction introduces magnetization-changing collisions, which dynamically frees the magnetization of the gas. We have thus observed a demagnetization of the BEC when the magnetic field is quenched below a critical value $B_c$ corresponding to a phase transition between a ferromagnetic and a non-polarized ground state. The phase transition is due to an inter-play between spin-dependent interactions and the linear Zeeman effect [2]. We have also studied the thermodynamic properties of spinor Cr atoms, and we have observed that above the critical field $B_c$, the ferromagnetic nature of BECs leads to the spontaneous magnetization of the cloud when BEC is reached [3]. I will also describe the control of magnetization-changing collisions in optical lattices. We investigate a scheme in which dipolar relaxation is resonant with the energy released in dipolar relaxation matches a band excitation resonance [4]. This scheme, which may produce correlated pairs of rotating states in each lattice site, can be viewed as the equivalent of the Einstein-de-Haas effect. Although rotation is not yet produced in our experiment, I will present first experimental results of these dipolar resonances, which show a pronounced anisotropic behaviour.

3This work was supported by the DARPA Optical Lattice Emulation Program, the NSF Physics Frontier Center at JQI, and the IARP Multiqubit Quantum Coherent Operations program through ARO contract.


3:00PM C1.00003 Ultracold Polar Gases. DEBORAH JIN, JILA/University of Colorado — Ultracold gases are powerful model systems for exploring interesting quantum many-body phenomena, and ultracold polar molecules open the possibility of studying systems with long-range interactions. At JILA, we make fermionic Kr molecules starting from an ultracold gas mixture of K and Rb atoms. We have observed and investigated atom-exchange chemical reactions in the ultracold polar molecule gas, and we are exploring polar molecules in optical lattice traps.

3:30PM C1.00004 Quantum phases of bosonic polar molecules in optical lattice geometries. BARBARA CAPOGROSSO-SANSONE, University of Oklahoma — In this talk I will address properties of a gas of polar bosonic molecules confined within single-, bi-, and multi-layer geometries — the molecular dipole moments are aligned perpendicularly to the layers. The results presented are based on Quantum Monte Carlo simulations. I will discuss phases and phase transitions displayed by such systems — with emphasis on solids and supersolids —, and the experimental conditions required to observe such phases. In the single layer geometry, I will focus on how the presence of atoms affects molecular solid phases stabilized by dipolar interactions, while in bi- and multi-layer geometries, my focus will be on the formation of pairs and multimers.
2:00PM C2.00001 Low-temperature, high-density magneto-optical trapping of potassium using the open \(4S \rightarrow 5P\) transition at 405 nm. DAVID MCKAY, DYLAN JERVIS, DAN FINE, University of Toronto. JOHN SIMPSON-PORCO, University of California Santa Barbara, GRAHAM EDGE, JOSEPH THYWISSEN, University of Toronto — We report [1] the laser cooling and trapping of neutral potassium on an open transition. Fermionic \(^{40}\text{K}\) is captured using a magneto-optical trap (MOT) on the closed \(4S_{1/2} \rightarrow 4P_{3/2}\) transition at 767 nm and then transferred, with unit efficiency, to a MOT on the open \(4S_{1/2} \rightarrow 5P_{3/2}\) transition at 405 nm. Because the \(5P_{3/2}\) state has a smaller line width than the \(4P_{3/2}\) state, the Doppler limit is reduced. We observe temperatures as low as 63(6) \(\mu\text{K}\), the coldest potassium MOT reported to date. The density of trapped atoms also increases, due to reduced temperature and reduced expulsive light forces. We measure a two-body loss coefficient of \(\beta = 2 \times 10^{-10} \text{cm}^3 \text{s}^{-1}\), and estimate an upper bound of \(8 \times 10^{-18} \text{cm}^2\) for the ionization cross section of the \(5P\) state at 405 nm. The combined temperature and density improvement in the 405 nm MOT is a twenty-fold increase in phase space density over our 767 nm MOT, showing enhanced pre-cooling for quantum gas experiments. A qualitatively similar enhancement is observed in a 405 nm MOT of bosonic \(^{41}\text{K}\).


2:12PM C2.00002 Direct laser cooling of yttrium monoxide. MATTHEW HUMMON\(^2\), MARK YEO, BENJAMIN STUHL, JILA, University of Colorado, Boulder, YONG XIA, East China Normal University, JUN YE, JILA, University of Colorado, Boulder — Using a laser system consisting of only three lasers, one for the main cooling transition and two for vibrational repumping, we create a quasi-closed optical cycling transition for the molecule yttrium monoxide (YO) capable of scattering more than one thousand photons. Using this laser system in conjunction with a cryogenic buffer-gas-cooled source we characterize the photon scattering rate by observation of deflection of the YO molecular beam. Additionally, we observe transverse Doppler laser cooling of the YO molecular beam.

\(^1\)We acknowledge support from the AFOSR and the NSF.

\(^2\)M. H. acknowledges support from an NRC Postdoctoral Fellowship.

2:24PM C2.00003 Trapped atom number in millimeter-scale magneto-optical traps. GREGORY W. HOTH, ELIZABETH A. DONLEY, JOHN KITCHING, National Institute of Standards and Technology — For compact cold-atom instruments, it is desirable to trap a large number of atoms in a small volume to maximize the signal-to-noise ratio. In MOTs with beam diameters of a centimeter or larger, the slowing force is roughly constant versus velocity and the trapped atom number scales as \(d^3\). For millimeter-scale MOTs formed from pyramidal reflectors, a \(d^6\) dependence has been observed [Pollack et al., Opt. Express, 17, 14109 (2009)]. A \(d^6\) scaling is expected for small MOTs, where the slowing force is proportional to the atom velocity. For a 1 mm diameter MOT, a \(d^6\) scaling results in 10 atoms, and the difference between a \(d^4\) and a \(d^6\) dependence corresponds to a factor of 1000 in atom number and a factor of 30 in the signal-to-noise ratio. We have observed > \(10^5\) atoms in 1 mm diameter MOTs, consistent with a \(d^4\) dependence. We are currently performing measurements for sub-mm MOTs to determine where the \(d^4\) to \(d^6\) crossover occurs in our system. We are also exploring MOTs based on linear polarization, which can potentially produce stronger slowing forces due to stimulated emission [Emile et al., Europhys. Lett. 20, 687 (1992)]. It may be possible to trap more atoms in small volumes with this method, since high intensities can be easily achieved.

2:36PM C2.00004 All-Optical Production of a Lithium Quantum Gas Using Narrow-Line Laser Cooling. TSUNG-LIN YANG, PEDRO M. DUARTE, RUSSELL A. HART, RANDALL G. HULET, Rice University — We have used the narrow \(2S_{1/2} \rightarrow 3P_{3/2}\) transition in the ultraviolet (UV) to laser cool and magneto-optically trap (MOT) \(^{6}\text{Li}\) atoms\(^1\). Laser cooling of lithium is usually performed on the \(2S_{1/2} \rightarrow 3P_{3/2}\) (D2) transition, and temperatures of \(\sim 300 \mu\text{K}\) are typically achieved. The linewidth of the UV transition is seven times narrower than the D2 line, resulting in lower laser cooling temperatures. We demonstrate that a MOT operating on the UV transition reaches temperatures as low as 59 \(\mu\text{K}\). Furthermore, we find that the light shift of the UV transition in an optical dipole trap at 1070 nm is small and blue-shifted\(^2\) facilitating efficient cooling from the UV MOT. After loading from the UV MOT, \(6 \times 10^6\) atoms with peak density \(n_0 = 2.7 \times 10^{13} \text{cm}^{-3}\) remain at \(T = 60 \mu\text{K}\), which corresponds to \(T/T_F \approx 2.7\). Evaporative cooling of a two spin-state mixture of \(^{6}\text{Li}\) in the optical trap produces a quantum degenerate Fermi gas with \(3 \times 10^6\) atoms in only 5 s.

\(^1\)Supported by NSF, ONR, DARPA, and the Welch Foundation.


M. Safronova, Personal Communication.

2:48PM C2.00005 ABSTRACT WITHDRAWN —

3:00PM C2.00006 Two Level Atom in Bichromatic Field: Von Neumann Entropy and Laser Cooling, ROBIN JEET SINGH, Department of Physics and Astronomy, Louisiana State University, Baton Rouge, LA-70803, PETR ANISIMOY, Physics and Astronomy Dept., Stony Brook University, Stony Brook, NY-11794, KIM BARNABAS, Department of Physics and Astronomy, Louisiana State University, Baton Rouge, LA-70803, HAROLD METCAlF, Physics and Astronomy Dept., Stony Brook University, Stony Brook, NY-11794, HWANG LEE, JONATHAN DOWLING, Department of Physics and Astronomy, Louisiana State University, Baton Rouge, LA-70803, QUANTUM SCIENCE AND TECHNOLOGY GROUP, DEPARTMENT OF PHYSICS AND ASTRONOMY, LOUISIANA STATE UNIVERSITY, METCAlF RESEARCH GROUP, PHYSICS AND ASTRONOMY DEPARTMENT, STONY BROOK UNI COLLABORATION — We present the analysis of entropy flow during the two-level atomic interaction with a bichromatic field in the absence of spontaneous emission. Jaynes Cummings approach was used to develop the numerical model describing the system. The two mode field was detuned from atomic transition. Our calculation for flow characterizes improvement in Carnot's efficiency for laser cooling. This suggests efficient cooling of atom over a wide range of temperature and thus may give a whole new dimension to the field of laser cooling.
3:12PM C2.00007 Sisyphus Cooling of Polyatomic Molecules, MARTIN ZEPPENFELD, BARBARA G.U. ENGERT, ROSA GLOECKNER, ALEXANDER PREHN, GERHARD REMPE, MPI for Quantum Optics — The long-range dipole-dipole interactions between polar molecules and their rich internal structure offer a multitude of experimentally unexplored possibilities for fundamental investigations at ultracold temperatures, ranging from many body physics to quantum information processing. Towards this end, a general approach to cool molecular ensembles akin to laser cooling for alkali atoms has been a much sought-after goal. In this talk, we present the experimental realization of opto-electrical cooling—a general Sisyphus-type cooling scheme for polar molecules. As a first result, an ensemble of $^{10}$ methyl-fluoride molecules has been cooled by more than a factor of 4 to 77mK, resulting in an increase in phase-space density by a factor of 7. The scheme proceeds in an electric trap, and requires only a single infrared laser with additional RF and microwave fields. The cooling cycle depends on generic properties of polar molecules and can thus be extended to a wide range of molecule species. Ongoing improvements in our trap design will allow cooling to sub-mK temperatures and beyond, opening wide-ranging opportunities for fundamental studies with polyatomic molecules at ultracold temperatures.


3:24PM C2.00008 The Construction and Properties of an AC-MOT, MELISSA ANHOLM, University of British Columbia, H. NORTON, R.M.A. ANDERSON, O. THERIAULT, J. DONOHUE, J.A. BEHR, TRIUMF — Magneto-Optical Traps (MOTs) have long been used to produce samples of cold trapped neutral atoms, which can be used in the measurement of a variety of physical quantities and theories. Until recently, one limitation of this type of trap was the necessity for the presence of a relatively large magnetic field which would decay only slowly after the trapping mechanism was turned off. This residual magnetic field is expected to partially destroy any atomic polarization induced, for example, by optical pumping. As a result, the precision of any physical measurement which requires polarization is limited. We will discuss the construction of our version of a newer type of MOT, the AC-MOT (originally developed by Harvey and Murray, PRL, 101, 173201 (2008)), which is designed specifically so as to minimize residual magnetic fields. We have found that our AC-MOT has lifetimes and cloud sizes similar to those we measured in our DC-MOT. We intend to use a trap similar to this in upcoming nuclear beta decay parity-violation measurements.

3:36PM C2.00009 Verifying the Reif model of MOT loading: Trap depth and density dependence1 JAMES BOOTH, British Columbia Institute of Technology, MAGNUS HAW, NATHAN EVETTS, WILL GUNTON, JANELLE VAN DONGEN, KIRK MADISON, University of British Columbia — We have studied the loading of rubidium atoms into a magneto-optical trap (MOT) with the aim of verifying a long-standing conjecture referred to as the Reif model. This model predicts that the loading rate should be proportional to the escape velocity of atoms from the trap to the fourth power, or equivalently, to the trap depth squared, and is directly proportional to the background rubidium atom density. The first prediction was confirmed by comparing the MOT loading rates to trap depths deduced from optical excitation of trapped atoms to a repulsive molecular potential. The rubidium density dependence was demonstrated by comparing the elastic collision-induced loss rate of atoms from a magnetic trap (MT) and the loading rate of a MOT: since the MT loss rate is proportional to the background density, the linear correlation to the MOT loading rate verified the Reif model. As a consequence of these findings, i) we have shown that the loading rates of different MOTs can be used as a convenient measure of their relative trap depths, and ii) we have experimentally determined the relationship between the capture and escape velocities in the MOTs studied (ranging in depth from 0.5 K to 1.8 K) to be $v_c = 1.29(0.12)v_e$.

1This work was supported by the Canadian Institute for Advanced Research, the Natural Sciences and Engineering Research Council of Canada, the Canadian Foundation for Innovation, and the BCIT School of Computing and Academic Studies.

3:48PM C2.00010 Cooling of particle ensembles with cooperative effects, GUJIN DAR LIN, SUSANNE YELIN, ITAMP, Harvard-Smithsonian Center for Astrophysics — Superradiance is known as speed-up of decay of an excited particle, essentially due to presence of near particles. Such cooperative effects can facilitate the cooling efficiency for certain particles who’s transition coupling strength is usually very weak so that the normal laser cooling cannot directly apply. We investigate the possibility and scenarios where this superradiance-assisted cooling can be put into practice.

Tuesday, June 5, 2012 2:00PM - 4:00PM —
Session C3 Focus Session: AMO Applications Grand Ballroom E - Chair: Elizabeth McCormack, Bryn Mawr College

2:00PM C3.00001 Low-energy electron interactions with biomolecules, CARL WINSTEAD, California Institute of Technology — Low-energy electron interactions with biomolecules have been the focus of sustained attention over the past decade. The demonstration by Sanche and coworkers that even subexcitation and subionization electrons can induce strand breaks in DNA opened a new frontier in understanding radiation damage to living systems. Many studies of DNA subunits and their analogues, both experimental and theoretical, have elucidated likely mechanisms by which slow electrons attach to and disrupt DNA, although the full picture is far from clear and some elements of it remain controversial. Increasing attention is also being given to low-energy electron collisions with amino acids in order to explore possible mechanisms of electron-mediated radiation damage to proteins. In a completely different context, electronic-biomolecule collisions are fundamental to spark ignition and combustion of biofuels such as methanol and ethanol. Not to be overlooked, either, is the simplest but most ubiquitous biomolecule of all, water, whose low-energy electron cross sections remain surprisingly ill-characterized. This talk will survey recent research that has been carried out in collaboration with experimentalists who undertake complementary measurements, allowing for useful comparisons to be made. Although the primary focus will be on electronically elastic collisions relevant to dissociative attachment and electron transport, electron-impact excitation cross sections for water will be presented and discussed.

1In collaboration with Vincent McCoy. Work supported by the Chemical Sciences, Geosciences, and Biosciences Division, Office of Basic Energy Sciences, Office of Science, U.S. DOE, and by NSF.

2:30PM C3.00002 Atom counting system to measure ultra-low Kr-85 contamination in liquid xenon dark matter detectors, TAE HYUN YOON, LUKE GOETZKE, ANDRE LOOSE, ELENA APRILE, TANYA ZELEVINSKYY, Columbia University — The XENON experiment aims at the direct detection of dark matter in the form of Weakly Interacting Massive Particles (WIMPs) via their elastic scattering off Xe nuclei. To achieve the required sensitivity, it is necessary to suppress Kr contamination of Xe which causes background events in Xe targets through Kr-85 beta decay. Magneto-optical techniques are used to cool and trap metastable Kr atoms from a RF plasma discharge. Fluorescence from single trapped Kr atoms can be detected with a sensitive photodetector. The cold-atom apparatus has been initially tested with Ar to avoid contamination by Kr. Several recent improvements increase the capture efficiency, including source cooling and additional transverse cooling of the metastable atomic beam. Results from tests with Ar and single atom detection with Kr will be presented.
2:42PM C3.00003 DNA detection using Laser Transmission Spectroscopy1. CAROL TANNER, STEVEN RUGGIERO, FRANK LI, University of Notre Dame, ANDREW MAHON, Central Michigan University, MATTHEW BARNES, SCOTT EGAN, JEFFREY FEDER, DAVID LODGE, CHING-TING HWANG, ROBERT SCHAFER, University of Notre Dame — Laser transmission spectroscopy (LTS) is a new quantitative and rapid technique for measuring the size, shape, and number of nanoparticles in suspension. We report on the application of LTS as a novel detection method for species-specific DNA detection where the presence of one invasive species was differentiated from a closely related invasive sister species. The method employs carboxylated polystyrene nanoparticles functionalized with short DNA fragments that are complimentary to a specific target DNA sequence. In solution, the DNA strands containing targets bind to the tags resulting in a sizable increase in the nanoparticle diameter, which is rapidly and quantitatively measured using LTS. DNA strands that do not contain the target sequence do not bind and produce no size change of the carboxylated beads. The results show that LTS has the potential to become a quantitative and rapid DNA detection method and have additional applications for point-of-care medical diagnostics.

3:48PM C3.00007 Rotation of an optical angular interference pattern in a spiral phase plate etalon. YISA RUMALA, AARON LEANHARDT, University of Michigan, Ann Arbor — A spiral phase plate etalon fabricated from a transparent polymer with azimuthally varying thickness and non-zero reflectivity at both surfaces is used to create an optical angular interference pattern on the output plane of the device [1]. The angular interference pattern is observed to rotate as the laser frequency is varied, and compared to a computer model of the experiment based on shot noise limited assumptions. For an ultra-low finesse device, the angular interference pattern is calculated to rotate through a 2π radian angle when the laser frequency is varied by ∼100GHz with a sensitivity of a few MHz (∼0.1 radian rotation angle) as determined from fitting the data. This work extends the operation of the conventional Fabry-Perot etalon consisting of longitudinal interference fringes to include angular interference fringes, and is expected to have broad applications in optical frequency metrology, quantum optics and coherent control of atomic systems.

1 Supported by NDnano/MIND Center, Office of the Vice President for Research, College of Science, Departments of Physics and Biological Sciences, Center for Aquatic Conservation, and Great Lakes Protection Fund

2:54PM C3.00004 Low Energy Electron Scattering from Fuels1. M. CRISTINA A. LOPES, Universidade Federal de Juiz de Fora — We report an investigation of processes that occur during the ignition of the plasma and its consequences in post-discharge time for an internal combustion engine, in order to find that the plasma chemistry is a parameter to be used in cars that operate with lean mixtures air-fuel. The relevance of this theme has attracted much attention, and has been one of the subjects of collaboration between experimental and theoretical groups in the USA and Brazil. We have produced some basic information necessary to modeling spark ignition in alcohol- fueled engines. Total cross sections of electron scattering by methanol and ethanol molecules were obtained, using the linear transmission method based on the Beer-Lambert law to first approximation. Measurements and calculations of differential cross sections for low-energy (rotationally unresolved) electron scattering were also obtained, for scattering angles of 5°~130°. The measurements were taken using the relative flow method with an aperture source, and calculations using two different implementations of the Schwinger multichannel method, one that takes all electrons into account and is adapted for parallel computers, and another that uses pseudopotentials and considers only the valence electrons. Additionally to these, computer simulation studies of binary collision of electron in mixtures of ethanol were performed, using a Zero-Dimensional Plasma Kinetic solver. Previous reported models for combustion of ethanol and cross sections data for momentum transfer of electron collisions with ethanol were used. The time evolutions of the main species densities are reported and the ignition time delay discussed.

3:24PM C3.00005 Green astro-comb for exoplanet searches. CHIH-HAO LI, ALEXANDER GLENDAY, NICHOLAS LANGLELLIER, GABOR FURESZ, Harvard-Smithsonian, MATTHEW WEBBER, Northeastern University, GUOQING CHANG, LI-JIN CHEN, HUNG-WEEN CHEN, JINKANG LIM, FRANZ KAERTNER, Massachusetts Institute of Technology, DAVID PHILLIPS, ANDREW SZENTGYORGYI, RONALD WALSWORTH, Harvard-Smithsonian — Astro-combs, a combination of a laser frequency comb, coherent wavelength shifting mechanism (such as a doubling crystal or photonic crystal fiber) and a mode-filtering Fabry-Perot cavity (FPC), are promising spectrograph calibrators, which will enable searches for Earth-like exoplanets and direct observation of the accelerating expansion of the universe. In this talk, I will present recent results from a green astro-comb, which will be integrated in 2012 with the HARPS-N spectrograph in the 3.6 m Telescopio Nazionale Galileo (TNG) in the Canary Islands. The green astro-comb consists of 6000 lines equally spaced by 20 GHz in the 500-600 nm optical band. The green astro-comb is generated from a 1-GHz Ti:Sapphire comb laser, a custom tapered photonic crystal fiber that spectrally shifts the comb lines to the visible, and two mode-filtering FPCs that increase the line spacing to be suitable for calibration of the λ=100,000 HARPS-N spectrograph. We have also used a high-resolution Fourier Transform Spectrometer (FTS) to analyze systematic errors across the full green astro-comb spectrum. The current status of these investigations will be presented.

3:36PM C3.00006 Wave packet dynamics for atomic projectile in solid film. GENNADIY FILIPPOV, Cheboksary Polytechnic Institute (branch) of the Moscow State Open University — The physics of phenomena extended during the passage of a swift atomic projectile through solid has a long history. A considerable amount of works was performed and a wide class of the so-called orientation phenomena was revealed. The theory of such phenomena usually based on assumption on a strength spatial localization of massive accelerated particles (nucleons, nuclei) having a sufficiently great velocity in a solid. The other point of view was proposed by Kagan & Kononetz, when it was stated a particle moving in a crystal should be described with the help of one Bloch wave and obviously should be delocalized. It was shown the channeling phenomena could be well described also with this theory. The width of a particle’s wave packet is important in some physical effects, e.g., in diffraction. With the help of density matrix calculation we show a sufficient information necessary to modeling spark ignition in alcohol- fueled engines. Total cross sections of electron scattering by methanol and ethanol molecules were obtained, using the linear transmission method based on the Beer-Lambert law to first approximation. Measurements and calculations of differential cross sections for low-energy (rotationally unresolved) electron scattering were also obtained, for scattering angles of 5°~130°. The measurements were taken using the relative flow method with an aperture source, and calculations using two different implementations of the Schwinger multichannel method, one that takes all electrons into account and is adapted for parallel computers, and another that uses pseudopotentials and considers only the valence electrons. Additionally to these, computer simulation studies of binary collision of electron in mixtures of ethanol were performed, using a Zero-Dimensional Plasma Kinetic solver. Previous reported models for combustion of ethanol and cross sections data for momentum transfer of electron collisions with ethanol were used. The time evolutions of the main species densities are reported and the ignition time delay discussed.

3:48PM C3.00007 Rotation of an optical angular interference pattern in a spiral phase plate etalon. YISA RUMALA, AARON LEANHARDT, University of Michigan, Ann Arbor — A spiral phase plate etalon fabricated from a transparent polymer with azimuthally varying thickness and non-zero reflectivity at both surfaces is used to create an optical angular interference pattern on the output plane of the device [1]. The angular interference pattern is observed to rotate as the laser frequency is varied, and compared to a computer model of the experiment based on shot noise limited assumptions. For an ultra-low finesse device, the angular interference pattern is calculated to rotate through a 2π radian angle when the laser frequency is varied by ∼100GHz with a sensitivity of a few MHz (∼0.1 radian rotation angle) as determined from fitting the data. This work extends the operation of the conventional Fabry-Perot etalon consisting of longitudinal interference fringes to include angular interference fringes, and is expected to have broad applications in optical frequency metrology, quantum optics and coherent control of atomic systems.

1 Supported by FAPESP, FAPEMIG, CNPq and at USA by NSF.

Tuesday, June 5, 2012 2:00PM - 4:00PM –
Session C4 Invited Session: Frontiers in Ultrafast X-ray Physics  
Garden 1-2 - Chair: Linda Young, Argonne National Laboratory
2:00PM C4.00001 Optical laser-based THz streaking for full FEL pulse characterization, ADRIAN CAVALIERI, University of Hamburg/MPSD/CFEL — Full temporal characterization of ultrashort, high brilliance x-ray pulses at Free Electron Laser (FEL) facilities, while elusive, will underpin their future use in experiments ranging from single-molecule imaging to extreme timescale x-ray science. This issue is especially acute when confronted with the characteristics of current generation FELs operating on the principle of self-amplified spontaneous emission, as most parameters fluctuate from pulse to pulse. We have achieved this crucial characterization by extending the techniques of photoelectron streaking originally developed for attosecond spectroscopy. In our experiments, high-intensity, optical laser generated single-cycle THz pulses were used to broaden and shift – or streak – the photoelectron spectrum of a noble gas target ionized by the incident FEL pulse. Due to the relatively long rise time of the THz streaking field (~600 fs), these measurements allow for the arrival-time and temporal profile of femtosecond to hundred-femtosecond FEL pulses to be determined simultaneously and on a single-shot basis. Optical laser-based THz streaking is suited for use over the full range of photon energies and pulse durations produced at FELs, from XUV to the hard x-ray regime. Experiments have now been performed at the hard x-ray Linac-Coherent Light Source at the SLAC National Accelerator Laboratory and at the XUV FEL at the LCLS free-electron laser in Hamburg. Distinct temporal features as short as 50 fs FWHM have been observed in the raw pulse profile prior to any correction for instrument resolution. While these first measurements have been resolution-limited, the potential for improvement to access the sub 10-fs range has also been demonstrated, which would allow for characterization and effective application of the shortest predicted, few-femtosecond x-ray pulses in the near future.

2:30PM C4.00002 Capturing ultrafast molecular dynamics with time-resolved x-ray absorption, x-ray emission, and x-ray scattering1, ANNE MARIE MARCH, Argonne National Laboratory — Ultrafast, time-resolved, laser-pump, x-ray-probe experiments are powerful tools for understanding and controlling the behavior of matter at the molecular level. Transient structural changes, both geometric and electronic, of single molecules after excitation by a laser pulse can be probed with high resolution and within complex or disordered environments, such as gases and liquids, taking advantage of the superior spatial resolution, elemental specificity and penetration power of x-rays. Third generation synchrotron sources, particularly the Advanced Photon Source (APS), provide x-rays with a unique combination of properties that are well suited for precision time-resolved measurements. These include a high flux (10^13 photons/second/0.01% bandwidth) that is distributed in short pulses (~100 ps) with moderate intensity (~10^7 photons/pulse) at a high repetition rate (MHz). Over the last decade laser-pump, x-ray-probe studies have been carried out at synchrotrons but a major challenge has been the low repetition rate (kHz) of standard amplified lasers resulting in underutilization of the synchrotron’s high flux. This limitation has recently been removed with the installation of a high repetition rate laser system at TID-D at the APS. In this talk I will discuss measurements on the light-induced switching of Fe(II) complexes at 3.26 MHz pump-probe repetition rates which efficiently use the available x-ray flux. This efficiency enabled the complementary techniques x-ray absorption spectroscopy (XAS), x-ray emission spectroscopy (XES) and liquid phase x-ray scattering (XRS) to be used simultaneously to collect information on the structural and electronic dynamics on the picosecond time scale.

3:00PM C4.00003 Time-resolved photoelectron emission from atoms and surfaces: the photo-effect revisited1, UWE THUMM, Kansas State University — Streaking spectroscopy experiments enable the resolution in time of photo-ionization processes at the natural time scale (tens of attoseconds, 1 as = 10^-16 seconds) of the motion of valence electrons in atoms and solids. This ultrahigh time resolution allows the observation of an apparent “delay-time” difference between the release and detection of photoelectrons from different initial states of atoms and solids. These delays are typically of the order of tens of attoseconds and are a measure of the net quantum phase that is accumulated during the entire photoemission process, including the release, propagation, and detection of the photoelectron. I will discuss different interpretations of and contributions to photoemission delay times based on the comparison of calculated time-resolved photo-electron spectra with recent experiments [1,2]. In particular, for time-resolved photo-emission from metal surfaces [3,4], we find our calculated electron spectra to be very sensitive to details in the modeling of dielectric-response and electron-propagation effects during the laser-assisted XUV excitation and emission process [5]. The sensitivity of photoemission time delays to the plasmonic response of solid surfaces suggests the time-resolved observation of collective (plasmonic, excitonic, etc.) excitations in atoms, nano-particles, and solids.

1 Work supported by the U.S. Department of Energy, Office of Basic Energy Sciences.

3:30PM C4.00004 Clusters in intense x-ray pulses, CHRISTOPH BOSTEDT, SLAC National Accelerator Laboratory — Free-electron lasers can deliver extremely intense, coherent x-ray flashes with femtosecond pulse length, opening the door for imaging single nanoscale objects in a single shot. All matter irradiated by these intense x-ray pulses, however, will be transformed into a highly-excited non-equilibrium plasma within femtoseconds. During the x-ray pulse complex electron dynamics and the onset of atomic disorder will be induced, leading to a time-varying sample. We have performed first experiments about x-ray laser pulse – cluster interaction with a combined spectroscopy and imaging approach at both, the FLASH free electron laser in Hamburg (Germany) and the LCLS x-ray free-electron laser in Stanford (California). Atomic clusters are ideal for investigating the light–matter interaction because their size can be tuned from the molecular to the bulk regime, thus allowing to distinguish between intra and inter atomic processes. Imaging experiments with xenon clusters show power-density dependent changes in the scattering patterns. Modeling the scattering data indicates that the optical constants of the clusters change during the femtosecond pulse due to the transient creation of high charge states. The results show that ultra fast scattering is a promising approach to study transient states of matter on a femtosecond time scale. Coincident recording of time-of-flight spectra and scattering patterns allows the deconvolution of focal volume and particle size distribution effects. Single-shot single-particle experiments with keV x-rays reveal that for the highest power densities an highly excited and hot cluster plasma is formed for which recombination is suppressed. Time resolved infrared pump – x-ray probe experiments have started. Here, the clusters are pumped into a nanoplasma state and their time evolution is probed with femtosecond x-ray scattering. The data show strong variations in the scattering patterns stemming from electronic reconfigurations in the cluster plasma. The results will be compared to theoretical predictions and discussed in light of current developments at free-electron laser sources.

Tuesday, June 5, 2012 2:00PM - 4:00PM _
Session C5 Bose Gases _ Garden 3 _ Chair: John Thomas, North Carolina State University
2:00PM C5.00001 Contact Measurements on Atomic BEC¹, PHILIP MAKOTYN, CATHERINE KLAUSS, JILA, ROBERT WILD, None, ERIC CORNELL, DEBORAH JIN, JILA — For ultracold fermions, a powerful set of universal relations, centered on a quantity called the contact, connects the strength of short-range two-body correlations to the thermodynamics of a many-body system with zero-range interactions [1]. An interesting question is whether these ideas and the concept of the contact can be extended to bosons, where issues include the decreasing stability of BECs with increasing repulsive interactions and the possibility of three-body interactions. We present measurements of the contact, using RF spectroscopy, for an ¹⁹⁸Rb atomic Bose-Einstein condensate (BEC) near a Feshbach resonance. To connect our measurements of the contact to three-body interactions, we located an Efimov resonance in ¹⁹¹Rb atoms with loss measurements and thus determine the three-body interaction parameter.


¹This work is supported by the NSF, ONR, and NIST.

2:12PM C5.00002 Effective renormalized multi-body interactions of harmonically confined ultracold neutral bosons, E. TIESSINGA, Joint Quantum Institute, P.R. JOHNSON, W.F. FLYNN, American University, D. BLUME, X.Y. YIN, Washington State University — We calculate the renormalized effective two-, three-, and four-body interactions for N neutral ultracold bosons in the ground state of an isotropic harmonic trap, assuming two-body interactions modelled with the combination of a zero-range and energy-dependent pseudopotential, and working to third-order in the free-space scattering length a at zero collision energy. The results account for quantum fluctuations to excited orbitals and finite-range effects. We show that the effective four-body interaction energy is U_4(\omega) = +(2.43317...|a/\sigma|^3 + O(a^4)), where \omega and \sigma are the harmonic oscillator frequency and its corresponding length, respectively. After renormalization the effective three-body interaction energy is U_3(\omega) = -(0.85576...|a/\sigma|^2 + 2.7921(1)|a/\sigma|^2 + O(a^4)).

In addition, we have performed independent numerical simulations for a finite-range boson-boson potential and comparison to the zero-range predictions reveals that finite-range effects must be included into account. In particular, we show that the energy-dependent pseudopotential captures the finite-range physics and in combination with multi-body effective interactions gives excellent agreement to the numerical simulations.

2:24PM C5.00003 ABSTRACT HAS BEEN MOVED TO K1.00089

2:36PM C5.00004 Nature of 3D Bose gases near Feshbach Resonance, MOHAMMAD S. MASHAYEKHI, DMITRY BORZOV, University of British Columbia, SHIZHONG ZHANG, Ohio State University, JUN LIANG SONG, Institute for Quantum Optics and Quantum Information of the Austrian Academy of Sciences, FEI ZHOU, University of British Columbia — we explore the nature of 3D Bose gases at large positive scattering lengths via resummation of dominating processes involving a minimum of virtual atoms. We focus on the energetics of Bose gases beyond the usual dilute limit. We also find that an onset instability sets in at a critical scattering length length beyond which the near-resonance Bose gases become strongly coupled to molecules and lose the metastability. Near the point of instability, the chemical potential reaches a maximum and the effect of the three-body forces can be estimated to be within a few percent.

2:48PM C5.00005 Narrow Feshbach Dance of Two Trapped Atoms, NICOLAS LOPEZ VALDEZ, University of California Riverside, EDDY TIMMERMANS, Los Alamos National Laboratory, SHAN-WEN TSAI, University of California Riverside — Near a narrow Feshbach resonance (with magnetic field width 10 mG or smaller) the ultra-cold atom interactions acquire an effective range that can be comparable to the average inter-particle distance. Although requiring a more accurate magnetic field control than their broad counterparts, the narrow Feshbach resonances can free cold atom physics from its straightjacket of the contact interaction paradigm. The finite-range effects can give rise to roton features in the phonon dispersion of dilute Bose-Einstein condensates (BEC’s) and BEC’s can support a ground state with modulated density patterns that breaks translational symmetry. We show that the finite range interaction is the consequence of the time-delay in atom-atom collisions. The narrow regime is also the parameter region in which the interacting atoms can spend a significant fraction of their time in the spin-rearranged (also called “closed”) channel. To study the interaction physics we describe two atoms in a harmonic trap, interacting near a narrow resonance. We find the fraction of time that the atoms spend in the closed channel at fixed magnetic field and we study the time evolution of this system under conditions of a time-varying magnetic field.

3:00PM C5.00006 Expansion Dynamics of a Ring Bose–Einstein Condensate¹, MARK EDWARDS, HADAYAT SEDDIQI, MICHAEL KRYGIER, BRANDON BENTON, Georgia Southern University, CHARLES CLARK, JQI and NIST — We studied the dynamics of BECs when released from a ring trap under conditions similar to those that obtained in a recent experiment done at NIST. In that experiment a ring–shaped BEC was formed in an all-optical trap created by intersecting a horizontal light sheet and a vertical Laguerre-Gaussian beam. Condensates were created in these traps and then “stirred” by applying Raman pulses having orbital angular momentum (OAM). We modeled the dynamics of condensates formed under these conditions by first solving the 2D time–dependent Gross–Pitaevskii equation (GPE) in imaginary time to obtain the initial condensate shape. We accounted for the OAM by applying a phase imprint to this wave function and then propagated it using the GPE in real time with the trap off. We found that, after release, the condensate expands both inward and outward. When no OAM was applied, this inward expansion causes the hole in the ring to close up entirely in turn causing a buildup of atom density there. Inflow and outflow of atoms from the center caused expanding interference rings to form. With non-zero applied initial OAM similar behavior was observed except that the central hole never closes with hole size increasing with increasing initial OAM. We compare our results with the

³Work supported by NSF grant numbers PHY–0758111 and PHY–1068761.

3:12PM C5.00007 2D Bose–Einstein Condensate Expansion Variational Model¹, HADAYAT SEDDIQI, MARK EDWARDS, MICHAEL KRYGIER, BRANDON BENTON, Georgia Southern University, CHARLES CLARK, JQI and NIST — We developed a set of coupled equations to approximate the dynamics of an expanding Bose-Einstein condensate (BEC) properly described by the 2D Gross–Pitaevskii equation (GPE). These equations apply to the case where the condensate is initially confined in one dimension and only weakly in the plane transverse to this direction. The equations were derived using a hybrid Lagrangian Variational Method (LVM) where the trial wave consisted of a completely unspecified function of the coordinates in the plane of weak confinement multiplied by a gaussian function of the transverse coordinate whose width and quadratic phase are variational parameters. The resulting equations consist of a 2D GPE whose nonlinear term is inversely proportional to the time-dependent transverse gaussian width coupled to an equation of motion for the width. The equation of motion for the gaussian width contains a term in which the integral of the fourth power of the 2D GPE solution appears. This factor represents the interaction energy of the confined 2D BEC. This method is applied to model recent experiment with BECs confined in ring–shaped potentials and the solutions are compared to solutions of the full 3D GPE as well as to the results of these experiments.

¹Work supported by NSF grant numbers PHY–0758111 and PHY–1068761.
3:24PM C5.00008 Effective interactions of ultracold bosons in anisotropic and anharmonic potentials, PHILIP JOHNSON, American University; EITE TIESINGA, JQI, NIST Gaithersburg and University of Maryland; XIANGYU YIN, DOERTE BLUME, Washington State University — We have recently calculated effective 2-, 3-, and 4-body interactions for ultracold bosons in an isotropic (spherical) harmonic trap. But for the important case of optical lattice potentials these results provide only a rough estimate of the effective multibody interactions in the small scattering length regime. In this talk we extend our model and results to anisotropic and anharmonic potentials. For example, we find anharmonic corrections as large as 30-40% for the effective three-body interaction strength in typical optical lattice potentials. I also discuss non-perturbative behaviors of the multibody interactions.

3:36PM C5.00009 Construction of analytical many body wave functions for correlated bosons in a harmonic trap, PETER SCHMELCHER, YIANNIS BROUZOS, University of Hamburg; CENTER FOR OPTICAL QUANTUM TECHNOLOGIES TEAM — We develop an analytical many-body wave function to accurately describe the crossover of a one-dimensional bosonic system from weak to strong interactions in a harmonic trap. The explicit wave function, which is based on the exact two-body states, consists of symmetric multiple products of the corresponding parabolic cylinder functions, and respects the analytically known limits of zero and infinite repulsion for arbitrary number of particles. For intermediate interaction strengths we demonstrate, that the energies, as well as the reduced densities of first and second order, are in excellent agreement with high scale numerical calculations.

3:48PM C5.00010 Particle losses in Bose-Einstein condensates, KRZYSZTOF PAWLOWSKI, Center for Theoretical Physics PAS; DOMINIQUE SPEHNER, GIULIA FERRINI, FRANK HEKKING, ANNA MINGUZZI, Laboratoire de Physique et Modélisation, des Milieux Condensés, CNRS; CENTER FOR THEORETICAL PHYSICS; PAS COLLABORATION, LABORATOIRE DE PHYSIQUE ET MODÉLISATION, DES MILIEUX CONDENSÉS, CNRS COLLABORATION — The two mode coherent atomic state, so called SU(2) state, evolves in the presence of particle interactions to a highly entangled state. The Fisher information increases in the evolution to its maximal possible value. Thus, the system may be useful in the interferometry. Here we study its Fisher information decay due to particle losses. We explain in details new phenomena caused by these processes and finally their effect on the “usefulness” of two mode Bose-Einstein condensate for ultra precise measurements.

Tuesday, June 5, 2012 2:00PM - 4:00PM
Session C6 GPMFC: Invited Session: Precision Measurements and Applications to Fundamental Physics Garden 4 - Chair: Holger Mueller, University of California, Berkeley

2:00PM C6.00001 Precision Atom Interferometry, MARK KASEVICH, Stanford University — While the current generation of atom interferometer force sensors perform at levels which compete favorably with the existing state-of-the-art, the full potential of these sensors has yet to be realized. Advances in the quality of the atom optics used to manipulate atomic de Broglie waves, the brightness of the atomic sources, and attaining full control over the quantum many-body wavefunction of the ensemble of interfering particles all promise to bring the performance levels of these sensors to levels of precision which may have dramatic future scientific and technological impact. This talk will review the performance of the current generation of sensors, describe recent experimental efforts to push the limits of sensor performance, and discuss future applications. In particular, a recent demonstration of a large area atom interferometer (>100 photon recoil momenta) based on a sequence of high-order Bragg transitions will be presented. Application of this method to the development of next generation gravity wave detectors and tests of the Equivalence Principle will be discussed.

2:30PM C6.00002 Optical Lattice Clocks, CHRIS OATES, NIST — Since they were first proposed in 2003 [1], optical lattice clocks have become one of the leading technologies for the next generation of atomic clocks, which will be used for advanced timing applications and in tests of fundamental physics [2]. These clocks are based on stabilized lasers whose frequency is ultimately referenced to an ultra-narrow neutral atom transition (natural linewidths << 1 Hz). To suppress the effects of atomic motion/recoil, the atoms in the sample (∼10^10 atoms) are confined tightly in the potential wells of an optical standing wave (lattice). The wavelength of the lattice light is tuned to its “magic” value so as to yield a vanishing net AC Stark shift for the clock transition. As a result lattice clocks have demonstrated the capability of generating high stability clock signals with small absolute uncertainties (∼1 part in 10^16). In this presentation I will first give an overview of the field, which now includes three different atomic species. I will then use experiments with Yb performed in our laboratory to illustrate the key features of a lattice clock. Our research has included the development of state-of-the-art optical cavities enabling ultra-high-resolution optical spectroscopy (1 Hz linewidth) together with the large atom number in the optical lattice, we are able to achieve very low clock instability (< 0.3 Hz in 1 s) [3]. Furthermore, I will show results from some of our recent investigations of key shifts for the Yb lattice clock, including high precision measurements of ultracold atom-atom interactions in the lattice and the dc Stark effect for the Yb clock transition (necessary for the evaluation of blackbody radiation shifts).


3:00PM C6.00003 Ultrastable clocks for precision spectroscopy in a 87Sr optical lattice clock1, MICHAEL MARTIN, JILA, NIST, and University of Colorado — Optical interferometers are central components of many modern experiments (e.g., LIGO, cavity QED, optomechanics, and optical clocks). These experiments share a common thread: their precision is in many cases limited by fundamental thermo-mechanical noise within the interferometer. A focus of our current work has been to reduce the impact of this noise on the length stability of optical cavities used for laser stabilization, and we have achieved fractional frequency instability at the 10^-16 level in several systems. Of these systems, the new ultrastable clock laser at JILA has enabled us to explore the many-body physics of interactions in a 87Sr optical lattice clock. The impetus to continue improving laser stability has also led us, in collaboration with colleagues at PTB, beyond glasses typically employed in optical cavities for laser stabilization. By constructing an optical cavity out of monocrystalline silicon, we have been able to demonstrate laser linewidths below 35 mHz, and short-term instability below 1 x 10^-16. In this talk I will present these new developments in precision laser stabilization and how they relate to exploring the many-body nature of the JILA 87Sr optical lattice clock.

1We acknowledge funding from NIST, NSF, PTB, and QUEST
3:30PM C6.00004 Quantum optomechanics: exploring the interface between quantum physics and gravity. MARKUS ASPELMEYER, Vienna Center for Quantum Science and Technology (VCQ), University of Vienna — Massive mechanical objects are now becoming available as new systems for quantum science. Quantum optics provides a powerful toolbox to generate, manipulate and detect quantum states of motion of such mechanical systems — from nanomechanical waveguides of some picogram to macroscopic, kilogram-weight mirrors of gravitational wave detectors. Recent experiments, including laser-cooling of massive mechanical devices into their quantum ground state of motion, and demonstrations of the strong coupling regime provide the primary building blocks for full quantum optical control of mechanics, i.e. quantum optomechanics. This has fascinating perspectives for fundamental experiments and for quantum foundations: for example, the on-chip realization of quantum entanglement, together with their flexibility to couple to different physical systems, offers a novel perspective for solid-state quantum information processing architectures. At the same time, the mass and size of mechanical resonators provides access to a hitherto untested parameter regime of macroscopic quantum physics via the generation of superposition states of massive systems and of optomechanical quantum entanglement, which is at the heart of Schrödinger’s cat paradox. Finally, and somewhat surprisingly, due to the large available masses it becomes even possible to explore the fascinating interface between quantum physics and (quantum) gravity in table-top quantum optics experiments. I will discuss a few examples.

Tuesday, June 5, 2012 2:00PM - 4:00PM —
Session C7 Invited Session: Quantum Manipulations with Rydberg Atoms Terrace - Chair: Thad Walker, University of Wisconsin-Madison

2:00PM C7.00001 Non-linear optics using Rydberg atoms. CHARLES ADAMS, Durham University — We present recent work on cooperative non-linear optics where the non-linearity is mediated not directly by the interaction between light and matter, but indirectly by dipole-dipole interactions between light induced excitations. For the giant dipoles associated with transitions between highly excited Rydberg states, a single excitation induces a cooperative response of up to 1000 neighboring atoms, thereby greatly amplifying the effect of each photon. This amplifying mechanism results in strongly enhanced optical non-linearities, see J. D. Pritchard et al. Phys. Rev. Lett. 105, 193603 (2010), allowing the creation and control of non-classical states of light.

2:30PM C7.00002 Towards Quantum Information Processing Using Rydberg Blockade1. LARRY ISENHOWER, Univ. of Wisconsin, Madison — Neutral atoms show great promise for use as qubits for quantum information processing. Long coherence times combined with the large interactions available using Rydberg states lead to the possibility of high fidelity quantum operations. It is the strong coupling regime that makes these states suitable for quantum memories and quantum networks. In this regime, strong dipole-dipole interactions allow the creation of entangled states of many Rydberg atoms that may be used as a building block for a quantum computer. I will describe our progress towards creating entangled states of up to 15 atoms and present our work on improving the fidelity of our quantum gates and the methods we use to achieve this goal.

3:00PM C7.00003 Trapping Rydberg Atoms in an Optical Lattice1. SARAH E. ANDERSON, University of Michigan — Optical lattice traps for Rydberg atoms are of interest in advanced science and in practical applications. After a brief discussion of these areas of interest, I will review some basics of optical Rydberg-atom trapping. The trapping potential experienced by a Rydberg atom in an optical lattice is given by the spatial average of the free-electron ponderomotive energy weighted by the Rydberg electron’s probability distribution. I will then present experimental results on the trapping of 85Rb Rydberg atoms in a one-dimensional ponderomotive optical lattice (wavelength 1064 nm). The principal methods employed to study the lattice performance are microwave spectroscopy, which is used to measure the lattice’s trapping efficiency, and photo-ionization, which is used to measure the dwell time of the atoms in the lattice. I have achieved a 90% trapping efficiency for 85Rb 50S states by inverting the lattice immediately after laser excitation of ground-state atoms into Rydberg states. I have characterized the dwell time of the atoms in the lattice using photo-ionization of 50D2S1/2 atoms. In continued work, I have explored the dependence of the Rydberg-atom trapping potential on the angular orientation of the atomic wavefunction. Distinct angular states exhibit different trapping behavior in the optical lattice, depending on how their wavefunctions are oriented relative to the lattice planes. Specifically, I have measured the lattice potential depth of sublevels of 85Rb nD atoms (50≤n≤65) in a one-dimensional optical lattice with a transverse DC electric field. The trapping behavior varies substantially for the various angular sublevels, in agreement with theory. The talk will conclude with an outlook into planned experiments.

3:30PM C7.00004 Rydberg atom mediated polar molecule interactions1. HOSSEIN SADEGHPOUR2, ITAMP, Harvard-Smithsonian Center for Astrophysics — Manipulating Rydberg interactions in ultracold ensemble is currently in vogue due to the long-range nature of forces and large dipole moments. Interactions between ultracold Rydberg and ground state atoms lead for formation of exotic classes of Rydberg molecules with peculiar properties. A particular class of such homonuclear molecules was recently observed to exhibit linear Stark shifts, pointing to significant permanent electric dipole moments. The symmetry-breaking in these molecules is explained. Rydberg atom mediated coupling with polar molecules leads to formation of ultralong range polyanomalocenes, which can be employed to dramatically enhance the range of controlled interaction between polar molecules, to coherently control molecular orientation, and to individually address polar molecules in optical lattices. A number of scenarios are described.

1Work supported by NSF, IARPA, and DARPA.

3:00PM - 4:00PM —
Session D1 Poster Session I (4:00 pm - 6:00 pm) Royal Ballroom

D1.00001 ATOMIC AND MOLECULAR STRUCTURE AND PROPERTIES I —
D1.00002 Bethe-Salpeter equation applied to Energy Levels of Kaonic Hydrogen. DAVID OWEN, Physics Department, Ben Gurion University. ROGER BARRETT, Retired — We apply, for the first time, the spin-1/2 - scalar formalism derived by Owen (Phys. Rev. D42, 3534(1990);Found. of Phys. 24, 273(1994)) to the kaonic hydrogen. We generalized the previously derived formalism to include both the finite size of the kaon and proton and calculate the energy level including all recoil corrections. The developed formalism can be extended to all orders in $\alpha$ to and the case in which renormalization is required.

D1.00003 Microwave/RESIS technique for measurement of heavy ion properties1, STEPHEN LUNDEEN, JULIE KEELE, SHANNON WOODS, CHRIS SMITH, Colorado State University, CHARLES FEHRENBACK, Kansas State University — The subtle but distinctive patterns of binding energies of high-L Rydberg electrons bound to heavy positive ions reveal the ion properties, such as polarizabilities and permanent moments, that control the long-range interactions between ion and the Rydberg electron. A specialized experimental technique, Resonant Excitation Stark Ionization Spectroscopy (RESIS), facilitates study of these fine structure patterns in a wide variety of Rydberg systems. The simplest RESIS measurements use a Doppler-tuned $\text{CO}_2$ laser to selectively detect individual high-L Rydberg states in a fast Rydberg beam by resonant excitation to a much higher level, followed by Stark ionization and collection of the resulting ion. Much more precise studies use the selective RESIS excitation to detect direct microwave transitions between Rydberg levels of the same $n$. Recent microwave/RESIS studies of this type have determined many properties of the ions Th$^{4+}$[1], Th$^{3+}$[2], and Ni$^{3+}$[3]. Details of this method will be described, with particular attention to studies of multiply-charged Rydberg ions.


1Supported by the Chemical Sciences, Geosciences, and Biosciences Division of the Office of Basic Energy Sciences, Office of Science, U.S. Dept. of Energy

D1.00004 Current Status of Atomic Spectroscopy Databases at NIST1, ALEXANDER KRAMIDA, YURI RALCHENKO, JOSEPH READER, National Institute of Standards and Technology — NIST’s Atomic Spectroscopy Data Center maintains several online databases on atomic spectroscopy. These databases can be accessed via the http://physics.nist.gov/PhysRefData web page. Our main database, Atomic Spectra Database (ASD) has recently been upgraded to v. 4.1.1, which contains critically evaluated data for about 174,000 spectral lines and 92,000 energy levels of almost all elements in the periodic table. A new version 5.0 is to be released this year. It will be extended to include the ground states and ionization energies of all elements up to $\text{Ds}$ ($Z=110$) in all ionization stages with a new Web interface for displaying them. We continue maintaining and regularly updating our bibliography databases, ensuring comprehensive coverage of current literature on atomic spectra, including energy levels, spectral lines, transition probabilities, hyperfine structure, isotope shifts, Zeeman and Stark effects. We continue maintaining other popular databases such as the Handbook of Basic Atomic Spectroscopy Data, searchable atlas of spectra of Pt-Ne and Th-Ne lamps, and non-LTE plasma-kinetics code comparisons.

1Supported by grants from the Department of Energy and NASA.

D1.00005 EIT Noise Resonance Power Broadening: a probe for coherence dynamics, MICHAEL CRESCIMANNO, Dept. of Physics and Astro, Youngstown State Univ., SHANNON O'LEARY, Dept. Physics, Lewis and Clark, CHARLES SNIDER, Dept. of Physics and Astro, Arizona State Univ. — EIT noise correlation spectroscopy holds promise as a simple, robust method for performing high resolution spectroscopy used in devices as diverse as magnetometers and clocks. One useful feature of these noise correlation resonances is that they do not power broaden with the EIT window. We report on measurements of the eventual power broadening (at higher optical powers) of these resonances and a simple, quantitative theoretical model that relates the observed power broadening slope with processes such as two-photon detuning gradients and coherence diffusion. These processes reduce the ground state coherence relative to that of a homogeneous system, and thus the power broadening slope of the EIT noise correlation resonance may be a simple, useful probe for coherence dynamics.

D1.00006 Properties of rotationally excited $\text{H}_2^+$ from fine structure measurements of high-L Rydberg states of $\text{H}_2^+$, ERICA SNOW, SUNY Fredonia — Measurement of the fine structure pattern of high-angular momentum Rydberg states provides information about the basic properties of the ion core, such as the Quadrupole moment and polarizability. Resonant Excitation Stark Ionization Spectroscopy (RESIS) uses a Doppler-tuned $\text{CO}_2$ laser to resonantly excite transitions in a fast molecular beam, which are detected by Stark ionization. Reported here is the analysis of the fine structure measurements of the high-L Rydberg states of the rotationally excited ($R=2$) ground vibrational level of molecular hydrogen. This determines the Quadrupole moment and scalar and tensor dipole polarizabilities of $\text{H}_2^+$. The experimental progress made using a novel approach to the detection techniques of RESIS which will allow the first measurements of the higher rotational levels of $\text{H}_2^+$ that were previously unattainable due to their fast autoionization rates will also be discussed.

1Work supported by the National Science Foundation.

D1.00007 Quantum Assisted Sensing Using Rydberg Atom Electromagnetically Induced Transparency, HAOQUAN FAN, JON SEDLACEK, ARNE SCHWETTMANN, JAMES P. SHAFFER, University of Oklahoma, HARALD KÜBLER, TILMAN PFAUL, Universität Stuttgart — We present a method to probe AC electric fields with high sensitivity based on dark resonances in electromagnetically induced transparency (EIT) spectroscopy. The basic mechanism is to couple the electric field to a ladder-type Rydberg atom EIT system. Data from experiments using Cs and Rb will be shown to illustrate the method. The experiments take place in small (mm-µm) vapor cells. We discuss our experiments to push the electric field sensitivity of the method below 1µV/cm.

D1.00008 Evolution of Xe spectrum and ion charge under sudden incoming radiation1, MARCEL KLAPISCH, MICHEL BUSQUET, ARTEP, inc Ellicott City, MD21042 — Experiments [1] and simulations of Xe at high temperature were recently reported, due to the possible scaling of astrophysical radiative shocks [2]. We used the newest version of HULLAC [3] to compute energy levels, radiative and collisional transition rates and level populations in a Coronal Radiative Model for the ions Xe$^{9+}$ to Xe$^{44+}$ (36263 configurations), at electron temperature of 100 eV and due to the possible scaling of astrophysical radiative shocks [2]. We used the newest version of HULLAC [3] to compute energy levels, radiative and collisional transition rates and level populations in a Coronal Radiative Model for the ions Xe$^{9+}$ to Xe$^{44+}$ (36263 configurations), at electron temperature of 100 eV and.


1Supported by CRASH, U. Mich. Ann Arbor under agreement DE-FC52-08NA28616
D1.00009 Lifetime Measurements of Trapped $^{232}$Th$^{3+}$. MICHAEL DEPALATIS, MICHAEL CHAPMAN, Georgia Institute of Technology. In recent years, there has been considerable interest in the low lying nuclear isomer state of $^{232}$Th which is only several eV above the nuclear ground state $^1$. To date, several groups are taking a variety of approaches to finding and exciting this unique state $^2$, including the use of trapped Th$^{3+}$ ions. Despite this attention, few precise measurements have been made of atomic lifetimes. In this work we present experiments to measure the $6D_{3/2}$ and $6D_{5/2}$ states using laser cooled $^{232}$Th$^{3+}$ confined in a linear Paul trap.


D1.00010 Lifetime Measurements of the $2^1\Sigma^+_u$ and $4^1\Sigma^+_u$ states of Na$_2$. LUTZ HUWEL, ROY ANUNCIADO, Wesleyan University. We have measured lifetimes of individual ro-vibrational levels in the excited states of Na$_2$ using pump-probe resonant ionization. For the double well $2^1\Sigma^+_u$ state, we use a 2-photon scheme. Ground state Na$_2$ produced in a molecular beam is excited resonantly by the doubled output of a suitably tuned dye laser and then ionized by a photon (532 nm) from a delayed Nd:YAG laser. By adjusting the delay of the second laser, the population decay of the excited state was observed and its lifetime can be extracted. Moreover, by tuning the first laser to different ro-vibrational level, we were able to measure the lifetime as a function of vibrational quantum number. Initial data show a noticeable and systematic variation especially near the potential barrier. The overall magnitude of our results is consistent with the average value of 52.5 ns reported for states below the barrier.

For the $4^1\Sigma^+_u$ state, we employed a double resonance technique via the A$^1\Sigma^+_u$ ($v=19$, J=20) state followed by one-photon (1064 nm) delayed ionization from a third laser. Our experimental method, analysis and results, showing vibrational state dependence here as well, will be presented.


D1.00011 Long Range Rydberg Molecules. HYUNWOOK PARK, THOMAS GALLAGHER, University of Virginia. A pair of Rydberg atoms can interact through the long range dipole-dipole interaction, leading to both attractive and repulsive potential curves at long range. Since there are many Rydberg levels, there are at shorter range avoided crossings between potentials of the same symmetry, forming potential wells. The depths and locations of the wells are dictated by the spacings of the atomic levels. Here we describe how the application of a static (or off resonant) rf field can be used to create such wells. Consider a pair of stationary atoms in the ns$_{1/2}$ and np$_{1/2}$ states. A weak electric field lifts the degeneracy of the np$^1_3$ml$^3_1$ levels, splitting them by $\Delta$. Choosing the field direction as the quantization axis, there are four states of total M$_J=1$. Two of the states connect to R=$\infty$ states containing m$_J=1/2$, and two to states containing m$_J=3/2$. The latter two states have no dipole-dipole interaction with each other, only with the states connected to m$_J=1/2$ at R=$\infty$. Thus, for large R their potential curves are flat, and if the R=$\infty$ m$_J=3/2$ level lies above the m$_J=1/2$ level a potential well is formed by the intersection of the M$_J=1$ curves. Its depth and the location of its minimum are controlled by the Stark shift. Calculations show that the well is quite broad in $\theta$, the angle between the quantization axis and the internuclear axis. Other examples of wells will be given.

$^2$This research is supported by The Air Force Office of Scientific Research.

D1.00012 PHOTON INTERACTIONS WITH ATOMS, IONS, AND MOLECULES I.

D1.00013 Photodissociation-Photoionization of Bromomethanes. JUAN C. POVEDA, ALFONSO GUERRERO, IGNACIO ÁLVAREZ, CARMEN CISNEROS, Instituto de Ciencias Físicas - UNAM, LEAM - ESCUELA DE QUÍMICA - UIS COLLABORATION. Molecular photodissociation—photoionization of bromomethanes were measured employing the laser-time of flight technique. By using molecular beams of different bromomethanes produced by adiabatic expansion (CH$_3$Br$_2$, CHBr$_3$, CBr$_4$), interacting with laser radiation of 266 and 355 nm from a Nd:YAG, pulse widths of 3.5-4.5 and 5.5-6.5 ns, respectively; and intensities of the order of 109 to 1010 Wcm$^{-2}$. Ions resulting of the interaction molecule-photon processes were analyzed using an R-ToF mass spectrometer. At the intensities of radiation used in the experiments, multiphoton processes are possible. From experimental data, we observed that the bromomethanes fast dissociate previous to the ionization, and molecular parents ions were not detected at the used wavelengths. The main detected ions correspond to H$^+$, C$^+$, CH$^+$, Br$^+$, CBr$^+$, CHBr$^+$, and CBr$_2^+$. These are the result of molecular dissociation when the original molecules absorb one photon forming neutral radicals, absorption of additional photons produces the ionization. From experimental data, we could calculate the number of absorbed photons needed to the ionization processes, being it of the order of two and three photons at 266 nm, three, and four at 355 nm. Detected ions and the precursors play an important role in the chemistry and physics of the atmosphere; they can interact with water and ozone molecules, evolving in the deterioration of the air quality.

$^1$CONACyT Grant 82521, and DGAPA-UNAM Grants IN108009 and IN107310

$^2$Escuela de Química - UIS

D1.00014 Radiation Damping in the Photoionization of Fe$^{14+}$. THOMAS W. GORCZYCA, Western Michigan University. MUHAMMET FATIH HASOGLU, Gazikent University, MANUEL A. BAUTISTA, Western Michigan University, ZINEB FELFLI, Clark Atlanta University, STEVEN T. MANSON, Georgia State University. We have completed a new theoretical investigation of photoabsorption and photoionization processes in Fe$^{14+}$, extending beyond an earlier frame transformation R-matrix implementation by performing fully-correlated, Breit-Pauli R-matrix calculations, to include both fine-structure splitting of the strongly-bound resonances and radiation damping effects. We find that radiation damping of 2p$\rightarrow$ nd resonances is important, giving rise to a resonant photoionization cross section that is significantly lower than the total photoabsorption cross section. Furthermore, our radiation-damped photoionization cross section is found to be in excellent agreement with recent EBIT measurements once a global shift in energy of $\approx-3.5$ eV is applied. These findings have important implications. Firstly, the use of EBIT experimental data is applicable only to photoionization processes and not to photoabsorption; the latter is required in opacity calculations. Secondly, our computed cross section shows a series of 2p$\rightarrow$ nd Rydberg resonances that are about 3.5 eV higher in energy than the corresponding experimental profiles, indicating that those threshold L-edge energy values currently recommended by NIST are likely in error by more than one eV.
D1.00015 Temperature Dependence of Rb 5P Fine-Structure Transfer Induced by $^4$He Collisions$^1$, M.A. GEARBA, University of Southern Mississippi, J.F. SELL, B.M. PATTERSON, R. LLOYD, J. PLYLER, R.J. KNIZE, US Air Force Academy — Employing ultrafast laser excitation and time-correlated single-photon counting, we have measured the fine-structure transfer between Rb 5P states induced by collisions with $^4$He buffer gas at temperatures up to 150°C. The temperature dependence of the binary cross-section agrees with earlier measurements while having almost an order of magnitude smaller uncertainty. Our data show that the temperature dependence of the three-body rate is about the same as that of the binary rate. The three-body rate can be described as arising from the reduction of the rubidium fine-structure splitting due to nearby helium atoms. Our fine-structure transfer studies are relevant for understanding alkali-inert gas atomic interactions as well as for practical applications in alkali laser development.

$^1$This work has been supported by the Air Force Office of Scientific Research and the National Science Foundation.

D1.00016 Velocity-Mapping Spectroscopy of the Ge$^-$, Sn$^-$, and Pb$^-$ Negative Ions, K-L. ATTICHART CHARTKUNCHAND, KYLE CARPENTER, VERNON DAVIS, PAUL NEILL, JEFFREY THOMPSON, AARON COVINGTON, Department of Physics and Nevada Terawatt Facility, University of Nevada, Reno, Reno, NV 89557 — Photoelectrons ejected from collisions between laser-produced photons and fast-moving beams of negative ions have been studied using the technique of Velocity-Map Imaging (VMI) spectroscopy. Digital images produced by the VMI spectrometer have been used to determine photoelectron kinetic energy spectra, as well as photoelectron angular distributions for select isoelectronic Group 14 anions. Analysis of these data are helping to clarify detailed structural properties of these ions with increasing Z and is providing dynamical information on the photon-ion collision systems.

D1.00017 Computational analysis of population transfer via STIRAP in sodium vapor, MATT TILLEY, J. BRUCE JOHNSON, CHAKREE TANJAROON, SUSAN ALLEN, Arkansas State University — We present a theoretical and computational analysis of STIRAP and SEP population transfer in sodium vapor as measured by fluorescence emission imaged onto a spectrometer. Calculations include 1) a careful analysis of the fraction of measured fluorescence output over all spatial positions in the incident beams and due to experimental geometry, 2) calculations of an unexpectedly strong effect on the STIRAP transfer efficiency with beams detuned between the D1 and D2 Fraunhofer lines, 3) a study of the relative efficiency of STIRAP and SEP on resonance at the D1 and D2 transitions, 4) the effects of varying pulse parameters (such as spatial shape, energy, focus) on transfer efficiencies, and 5) explorations of population transfer in sodium as a function of the pump-Stokes energy landscape. The system states are calculated utilizing a Hamiltonian which includes fine and hyperfine structure (two nine-state and four five-state transitions) of the 3s, 3p and 5s levels in sodium. The findings are compared to experimental results obtained using a picosecond laser system with linewidth very near the transform-limit (±15%).

D1.00018 Laser Interactions with Atomic and Molecular Positronium, DAVID CASSIDY, University of California, Riverside — Positronium (Ps), the bound state between an electron and its antiparticle, the positron, may be efficiently created by bombarding certain porous materials with intense bursts of positrons obtained from a positron accumulator. Using a Surko-type buffer gas trap we have produced a high-density pulsed positron beam that makes it possible to study interactions between Ps atoms, allowing for measurements of molecular Ps$_2$ formation and Ps-Ps scattering. Moreover, even at a low spatial density the ~ 1 ns wide pulses are well suited to laser spectroscopy of Ps atoms; numerous experiments are possible, including measurements of atomic energy intervals (e.g., the hyperfine interval), the effects of confinement on transition wavelengths, Ps cooling and the production of long-lived Rydberg Ps atoms. High density pulses used with lasers have also been used to perform optical spectroscopy on the Ps$_2$ system.

D1.00019 Photoabsorption spectrum of the Xe@C$_{60}$ endohedral fullerene$^1$, ZHIFAN CHEN, ALFRED Z. MZEZANE, Clark Atlanta University — Photoabsorption spectrum of the Xe@C$_{60}$ endohedral fullerene has been studied using the time-dependent-density-functional-theory (TDDFT), which represents the dynamical polarizability of an interacting electron system by an off-diagonal matrix element of the resolvent of the Liouvillian superoperator and solves the problem with the Lanczos algorithm. The method has been tested with the photoabsorption cross sections of the free Xe atom and C$_{60}$ fullerene. The result for the Xe@C$_{60}$ confirms the three main peaks observed in the recent measurement in the energy region of the Xe 4d giant resonance [1] and shows the possibility that the Auger decay of the Xe$^+$ has been greatly suppressed if the ion is encapsulated inside C$_{60}$. It is suggested to perform the same measurement around 22 eV to check this possibility.


$^1$Supported by DOE, AFOSR and Army Research

D1.00020 Photoionization of confined noble gas atoms: Hybridization and interchannel coupling effects$^1$, MOHAMMAD JAVANI, Georgia State University, HIMADRI S. CHAKRABORTY, Northwest Missouri State University, STEVEN T. MANSON, Georgia State University — A theoretical study of the photoionization of the noble gas atoms Ne, Ar, Kr and Xe confined endohedrally with a C$_{60}$ fullerene molecule is presented. The fullerene shell is represented by a jellium potential of 60 smeared out C$^{4+}$ ions and the wave functions 240 delocalized valence electrons plus the atomic electrons move in the field generated by the atomic potential plus the shell potential. The photoionization is calculated within the framework of the time-dependent local-density approximation (TDLDA) [1] which includes significant aspects of correlation. The results show that in all four cases, the valence photoionization channel cross sections of the entrapped atoms are dramatically increased by interchannel coupling with the C$_{60}$ plasmons. In addition, hybridization, the mixing of initial-state wave functions of atom and shell, occurs in a number of cases, a phenomenon which substantially alters the cross sections of both the atomic and the shell states. Confinement resonances are also in evidence for all cases. The evolution of these effects along the noble gas sequence is discussed.


$^1$This work is supported by NSF and DOE, Office of Chemical Sciences
D1.00021 Single photoionization with excitation and double photoionization of He endofullerenes1, T.-G. LEE, J.A. LUDLOW, M.S. PINDZOLA, Physics Department, Auburn University — Recently, using a non-perturbative time-dependent close-coupling (TDCC) method we investigated and confirmed the existence of these resonances in the double photoionization cross section of He@C_{60} [1, 2]. Here, we extend our previous studies to examine confinement resonances not only in the double photoionization process, but in the process of single photoionization with excitation for various He endofullerenes, namely He@C_{36}, He@C_{60} and He@C_{82}. We found He@C_{82} also displays confinement resonances in the double photoionization cross sections; while for He@C_{60} the confinement resonances are suppressed. For single photoionization leaving the He^+ ion in its ground state, we found the magnitude of the cross sections for the endofullerenes is comparable to that of helium. For single photoionization with excitation to the n=2 shell, the endofullerene cross sections showed a reduction as compared to bare He atoms; while for photoionization with excitation to the n=3 shell, the cross sections for the endofullerenes showed an enhancement. In addition, we also found confinement resonances in the single photoionization with excitation cross sections.


1This work was supported in part by grants from the US Department of Energy. Computational work was carried out at NERSC in Oakland, California.

D1.00022 Time delay in photoionization near Cooper minima, JOBIN JOSE, SINDHU KANNUR, ASHISH KUMAR, HARI R. VARMA, IIT-Mandi, PRANAWA C. DESHMUKH, IIT-Madras, STEVEN T. MANSON, Georgia State University — The connection between the energy dependence of the scattering phase shift and time delay is known [1]. With the developments of techniques in attosecond physics, it has become possible to measure the time delay between photoionization from different subshells [2, 3]. There have been several nonrelativistic calculations of the time delay between photoelectrons from different subshells [4, 5] that confirmed the need to include many-electron correlations. In the present work, the RRPA [6], which includes both relativity and many of the important electron correlation effects, is employed to calculate the time delay between photoelectrons from the valance ns, np_{3/2} and np_{1/2} subshells of noble gas atoms in the dipole approximation, and particularly dramatic variations occur in the vicinity of Cooper minimum [7] owing to the rapid variation of the scattering phase shift in the vicinity of Cooper minima, including effects that occur only due to relativistic splittings. These effects appear to be amenable to experimental investigation.


D1.00023 2s → np Autoionizing Resonances of the Neon Isoelectronic Sequence using RRPA and RMQDT1, NRISIMHA MURTY MADUGULA, MILIND V. RUNDHE, GOPALAN ARAVIND, PRANAWA C. DESHMUKH, IIT-Madras, STEVEN T. MANSON, Georgia State University — Extensive theoretical and experimental studies of the photoionization of various atoms and ions have been carried out over long period of time [1, 2] owing both to the fundamental importance of the process and to the many applications, e.g., astrophysical and atmospheric modeling, plasma dynamics, etc. In the present work, we report our studies of the 2e^+→np autoionizing resonances in the He isoelectronic sequence, of significance due to the cosmic abundance of these systems [2-4]. In particular, Ne, Na^+, Mg^{2+}, Al^{3+}, and Sc^{4+} have been studied. The study has been performed within the framework of the relativistic random-phase approximation (RRPA) [5] and relativistic multichannel quantum defect theory (RMQDT) [6]. The resonances have been characterized in terms of position, width and shape, i.e., Fano profiles [7, 8], and the evolution of the parameters of the resonances along the sequence has been investigated.


D1.00024 Theoretical Electronic Structure of Fluoromethanes and dissociation pathways1, JUAN C. POVEDA, ALFONSO GUERRERO, IGNACIO ALVAREZ, CARMEN CISNEROS, Laboratorio de Colisiones Atómicas Moleculares - Instituto de Ciencias Físicas - UNAM, LEAM - ESCUELA DE QUÍMICA - UIS COLLABORATION — Fluoromethanes (CH_{3-n}F_{n}, n=0-3) are compounds characterized by a high reactivity. They are liberated into the atmosphere as consequence of anthropogenic activity. In the higher atmosphere, they can dissociate by the interaction with UV photons and other energetic particles. From experiments in our laboratory we had observe that these compounds dissociate when they interact with high density of photons. In this work we attempt to explain the main dissociation mechanisms involved when these molecules interact with photons of 255 and 355 nm, and the resulting products are neutral fragments with one and two atoms. The first electronic states, S_0 to S_3 and T_1 to T_4, of above mentioned compounds were calculated using time dependent density functional theory along the C-F and C=O coordinates. From theoretical results we observe that C-F dissociation channel can be easy reached by the absorption of one photon of 266 or 355 nm, leading the formation neutral F and CH_{3-n}F_{n-1} (n=1-3). Another mechanism is a two step processes mediated by stable transition structures, the molecule can dissociate as F_2 and CH_{n}F_{2-n} (n=1,2).

1 CONACyT Grant 82521 and DGAPA-UNAM Grants IN108009 and IN107310

D1.00025 Plasmon-plasmon coupling in buckyionon fullerenes: Photoexcitation of interlayer plasmonic cross modes1, MATT MCCUNE, University of Missouri, Columbia, RUMA DE, Northwest Missouri State University, MOHAMED MADJET, CFEL, DESY, Hamburg, Germany, HIMADRI CHAKRABORTY, Northwest Missouri State University, STEVE MANSON, Georgia State University — Considering the photoionization of a two-layer fullerenon-onion system, C_{60}@C_{240}, strong plasmonic couplings between the nested fullerenes are predicted [1]. The resulting hybridization produces four cross-over plasmons generated from the bonding and antibonding mixing of excited charge clouds of individual fullerenes. The properties of these hybrid plasmons are also greatly different from the plasmons that exist in isolated C_{60} and C_{240}. This suggests the possibility of designing buckyions exhibiting plasmon resonances with specified properties as candidates for nanomaterial plasmonics. The results can further motivate future research to modify the resonances by exciting atoms, molecules or clusters in multi-layered fullerenes.


1Supported by the NSF and US DoE.
D1.00026 Kinetic Energy Release dependence in the Photo Double Ionization of H$_2$. TH. WEBER, S. MIYABE, A. BELKACEM, C.W. MCCURDY, LBNL, U. LENZ, T. JAHNKE, R. DOERNER, University of Frankfurt, J. WILLIAMS, A. LANDERS, Auburn University — In the Photo Double Ionization (PDI) of hydrogen molecules with photon energies of 150eV we were able to probe the electronic two particle density as a function of the bond length, i.e. the Kinetic Energy Release (KER) of the ions, and the orientation of the molecular axis with respect to the polarization vector of the incoming light. We applied the COLTRIMS technique and measured two electrons and two protons in coincidence. We found a shift in the KER for $\sigma$ and $\pi$ transitions. While the KER is lower when the molecular axis is aligned parallel to the linear polarization vector ($\sigma$) than the KER for a perpendicular orientation ($\pi$) is clearly higher by a little more than 1eV. Quantum mechanical ab initio calculations are able to quantify the shift in KER and the ratio for the two different transitions ($\beta$-parameter) for a broad range of photon energies (75 to 240eV). These results reflect the dependence of the $\sigma$ and $\pi$ amplitudes to the bond length. This shows that a simple KER measurement for horizontal and vertical polarization can be used to extract this information; it makes measuring the $\beta$-parameter as a function of KER obsolete.

D1.00027 Photofragmentation of Fullerene Molecular Ions. KIRAN BARAL, NAGENDRA ARYAL, DAVID ESTEVES, CHRISTOPHER THOMAS, RONALD PHANEUF, University of Nevada, Reno, DAVID KILCOYNE, Lawrence Berkeley National Laboratory — Experimental results are reported for single ionization and ionization with fragmentation of the fullerene molecular ions C$_{60}^+$ and C$_{70}^+$ after excitation by monochromatized vacuum ultraviolet synchrotron radiation at different photon energies: 22 eV, 35 eV, 65 eV, 105 eV and 140 eV. Since fullerenes are composed of even numbers of carbon atoms, the fragmentation occurs by the loss of differing numbers of carbon atom pairs. The energy dependences of relative cross sections for direct x-ray ionization of a core electron. We use the boosted HHG radiation from presented. This work is supported by the Division of Chemical Sciences, Geosciences and Biosciences of the U.S. Department of Energy.

D1.00028 The vibration-dependent electron anisotropy in O$_2^-$ photodetachment. MICHAL TARANA, CHRIS H. GREENE, Department of Physics and JLLA, University of Colorado, Boulder, Colorado 80309-0440, USA — Recent experimental work [1] reports observation of a significant vibrational dependence of the photoelectron angular distributions (PADs) recorded for the O$_2$(X$^2\Sigma^+_g$) → O$_2$(X$^2\Pi^+_g$) band. It is the aim of the theoretical model presented here to reproduce the experimental results, allow for a deeper insight into the mechanism of this process and explain the sensitivity of the PAD to vibronic coupling in the anion ground electronic state. The vibrational dynamics is treated using the vibrational frame transformation [2], the K-matrices in the fixed-nuclei approximation are obtained from the $ab$ initio $R$-matrix calculations.


3 This work was supported in part by the Department of Energy, Office of Science.

D1.00029 Acceleration of proton bunches by petawatt chirped radially-polarized laser pulses. YOUSEF SALAMIN, Department of Physics, American University of Sharjah, United Arab Emirates, BENJAMIN GALOW, JIAN-XING LI, CHRISTOPH KEITEL, Max Planck Institute for Nuclear Physics, Heidelberg, Germany — Results from theoretical investigations will be presented which show that photons can be accelerated from rest to a few hundred MeV by a 1 PW chirped radially-polarized laser pulse of several femtosecond duration and focused to a waist radius comparable to the radiation wavelength. Single-particle calculations are supported by many-particle and particle-in-cell simulations. Compared with laser acceleration by a similar linearly-polarized pulse, the gained energies are less, but have better beam quality. For a suitable initial phase, a particle bunch gets accelerated by the axial component $E_z$ of the laser pulse and, initially focused by the transverse electric field component $E_y$. Beam diffraction finally sets in due to the particle-particle Coulomb repulsion, after interaction with the pulse ceases to exist.

D1.00030 High-order harmonic generation enhanced by x rays from free-electron lasers. CHRISS-TIAN BUTH, Argonne National Laboratory, MARKUS Č. KOHLER, Max-Planck-Institut fur Kernphysik, FENG HE, Shanghai Jiao Tong University, KAREN Z. HATSAGORTSyan, Max-Planck-Institut fur Kernphysik, JOACHIM ULLRICH, Max-Planck-Institut fur Kernphysik and Max Planck Advanced Study Group at CFEL, CHRISTOPH H. KEITEL, Max-Planck-Institut fur Kernphysik — We theoretically examine high-order harmonic generation (HHG), by an intense near-infrared (νIII) light, in the emerging, intense x-ray free electron lasers (FELs) which have started to revolutionize x-ray science. We present two theories based on modified three-step models of the emerging HHG. Once, we combine HHG with resonant x-ray excitation of a core electron into the transverse valence vacancy that is created in the course of the HHG process via tunnel ionization (first step of HHG) by the nIR light. When the continuum electron is driven back to the parent ion, a recombination with the valence and the core hole may occur. Modified HHG spectra are determined and analyzed for krypton on the $3d^1 \rightarrow 4p$ resonance and for neon on the $1s^2 \rightarrow 2p$ resonance. Another time, we examine HHG where tunnel ionization by the νIII light is replaced by direct x-ray ionization of a core electron. We use the boosted HHG radiation from 1e electrons of neon to predict single attosecond pulses in the kiloelectronvolt regime. For both presented schemes, we show large HHG yields from the recombination of the continuum electron with the core hole. Our research brings the capabilities of HHG-based sources to FELs.

D1.00001 Development of a High Harmonic Beamline for Time-Resolved XUV Spectroscopy. EMILY SISTRUNK, JAKOB GRILJ, MARKUS GUEHR, PULSE Institute and Chemical Science Division, SLAC, Menlo Park, CA 94025 — In order to better understand and control the electronic dynamics occurring during such phenomena. Extreme ultraviolet (XUV) light induces transitions between narrowly confined core electronic states and valence states. Thus ultrafast XUV absorption provides a route to determine electron distributions during chemical change. We present the design of our new femtoseconds XUV absorption spectrometer. The XUV pulses are generated in a rare gas cell in a high harmonic generation (HHG) process. Strong laser field HHG yields a promising probe source in the 10-100 eV energy range, making it an ideal tool for XUV absorption spectroscopy of molecules containing 3d transition metals with $M_{4,5}$ edges between 40-70 eV. The femtosecond duration pulses intrinsically produced by HHG allow for the necessary temporal resolution. We plan to study organometallic molecules such as the transition metal carbonyls which undergo ligand dissociation under the influence of ultraviolet light. After UV excitation a radiationless non-Born-Oppenheimer transition metal carbonyls which undergo ligand dissociation under the influence of ultraviolet light. After UV excitation a radiationless non-Born-Oppenheimer dynamics is important to the general field of photocatalysis. This work is supported by the Office of Science Early Career Research Program.

D1.00032 Probing the Sub-cycle AC Stark Shift by means of Attosecond Pulses: An $ab$ initio Study of Transient Absorption. DI ZHAO, Xi’an Jiaotong University, Xi’an, China, University of Kansas, DMITRY A. TELNOV, St.Petersburg State University, Russia, SHIH-I. CHU, University of Kansas — We report a first fully $ab$ initio theoretical exploration of the sub-cycle dynamical AC Stark shift and broadening of He atoms driven by an attosecond pulse and IR pulse. Since the duration of the UV pulse is much shorter than that of the optical cycle of the IR dressing laser field, the sub-cycle dynamics of the dressed system can be unfolded by applying the attosecond pulse at different time delay. A nonperturbative method is developed to calculate the transient absorption spectrum without weak-field limitation. By solving the time-dependent Schrödinger equation accurately by means of the time-dependent generalized pseudospectral method, we predict novel sub-cycle laser-induced time-dependent AC Stark shift and power broadening of He atoms whose dynamical features are in good agreement with the latest ongoing experiments at UCF. Detailed results will be presented. This work is partially supported by DOE and NSF.
D1.00033 Revisiting molecular ionization: Does a molecule like to share?1, C.B. MADSEN, B.D. ESRY, J.R. Macdonald Laboratory, Department of Physics, Kansas State University — The ever-increasing detail obtained in strong-field experiments calls for a deeper understanding of the laser-molecule interaction. For instance, recent measurements reported in PRL 107, 143004 (2011) reveal a limitation in understanding strong-field ionization dynamics in terms of the strong-field approximation. We have addressed the question of how the electron and the nuclei share the energy when H$_2^+$ breaks up in the presence of an intense IR field via the process: H$_2^+$ + n$\hbar$ω → p + p + e$^-$. Solving the time-dependent Schrödinger equation and calculating the ionization probability resolved as a function of the asymptotic electron energy and the nuclear kinetic energy release (KER) allow us to give an answer. The energy sharing is non-trivial and plays an important role in the prediction of, for instance, the KER. We also address the limitations of current understanding of molecular ionization by comparing to models like the strong-field approximation and the Floquet picture. Such benchmarking may be facilitated by XUV+IR pump-probe schemes and carrier-envelope-phase control that allow for time-resolved and spatial probing of the dynamics.

1Supported by the Chemical Sciences, Geosciences, and Biosciences Division, Office of Basic Energy Sciences, Office of Science, U.S. Department of Energy.

D1.00034 Dissociation dynamics of O$_2^+$ in intense laser fields$^{1}$, M. MAGRAKVELIDZE, Department of Physics, Kansas State University, C.M. AIKENS, Department of Chemistry, Kansas State University, S. DE, Saha Institute of Nuclear Physics, India, C.L. COCKE, U. THUMM, Department of Physics, Kansas State University — We studied the nuclear dynamics of diatomic molecular ions in intense infrared laser fields by analyzing their fragment kinetic energy release (KER) spectra as a function of time [1]. We found that, in general, ionization of the neutral parent molecule by an ultra-short pulse populates several intermediate electronic states of the molecular ion that contribute to the same KER. Within the Born-Oppenheimer (BO) approximation, we calculated ab-initio adiabatic potential energy curves for the molecular ions and their electric dipole-couplings, using the quantum chemistry code GAMESS [2]. By comparing KER spectra that result from the nuclear dynamics on individual and on dipole coupled BO potential curves with that measured for O$_2$ molecules, we developed a scheme for identifying intermediate states of the molecular ions that are relevant during the dissociation dynamics.

[1] S. De et al., PRA 80, 011404 (2009); S. De et al, PRA 84, 043410 (2011)

1Supported by the US DOE and NSF.

D1.00035 An assessment of tunneling-multiphoton dichotomy in atomic photo-ionization: Keldysh parameter versus scaled frequency$^1$. TURKER TOPCU, FRANCIS ROBICHEAUX, Auburn University — It is common practice in strong-laser physics community that dynamical regime of atomic ionization is described by the Keldysh parameter, $\gamma$. Two distinct cases where $\gamma \ll 1$ and $\gamma \gg 1$ are associated with ionization mechanisms that are predominantly in tunneling and in multi-photon regimes, respectively. We report on our fully three-dimensional ab initio quantum simulations of ionization of hydrogen atoms in laser fields described in terms of the Keldysh parameter by solving the corresponding time-dependent Schrödinger equation. We find that the Keldysh parameter is useful in inferring the dynamical ionization regime only when coupled with the scaled laser frequency, $\Omega$, when a large range of laser frequencies and peak intensities are considered. The additional parameter $\Omega$ relates the laser frequency $\omega$ to the classical Kepler frequency $\omega_K$ of the electron, and together with the Keldysh parameter, they can be used to refer to an ionization regime.

1This work was supported by the Office of Basic Energy Sciences, U.S. Department of Energy. Computational work was carried out at the National Energy Research Scientific Computer (NERSC) Center in Oakland, CA.

D1.00036 Size dependent ionization dynamics of argon clusters in intense x-ray pulses, SEBASTIAN SCHORB, LCLS, SLAC National Accelerator Laboratory, D. RUPP, Technische Universität Berlin, M. SWIGGERS, R.N. COFFEE, M. MESSERSCHMIDT, G. WILLIAMS, J.D. BOZEK, S.-I. WADA, LCLS, SLAC National Accelerator Laboratory, T. MÖLLER, Technische Universität Berlin, C. BOSTEDT, LCLS, SLAC National Accelerator Laboratory — Free Electron Lasers open the door for novel experiments in many science areas ranging from ultrafast chemical dynamics to single shot imaging of molecules. For the success of virtually all experiments with free electron lasers a detailed understanding of the light - matter interaction in the x-ray regime is pivotal. The Linac Coherent Light Source (LCLS) free electron laser in Stanford allows for the first time to study inner shell ionization dynamics of intense x-ray pulses on a femtosecond time scale. We performed experiments on the ionization dynamics of Argon clusters at different pulse length using the slotted spoiler foil in the second LCLS bunch compressor [1]. The Auger rate of argon clusters is predicted to be size dependent and lower than in atoms due to delocalization of the valence electrons [2]. We observe a dependence of the ionization dynamics on pulse length and cluster size. The results are discussed and also compared to recent atomic and molecular data from LCLS.


D1.00037 Quantum dynamics in strong fields with Fermion Coupled Coherent States, ADAM KIRLANDER, ITAMP, Harvard-Smithsonian Center for Astrophysics, Cambridge, MA 02138, USA, DIMITRII V. SHALASHILIN, School of Chemistry, University of Leeds, Leeds LS2 9JT, United Kingdom — We present a new version of the Coupled Coherent State method, specifically adapted for solving the time-dependent Schrödinger equation for multi-electron dynamics in atoms and molecules. This new theory takes explicit account of the exchange symmetry of fermion particles, and uses fermion molecular dynamics to propagate trajectories. As a demonstration, calculations in the He atom are performed using the full Hamiltonian and accurate experimental parameters. Single and double ionization yields by 160 fs and 780 nm laser pulses are calculated as a function of field intensity in the range 10$^{14}$ - 10$^{16}$ W/cm$^2$ and good agreement with experiments by Walker et al. is obtained. Since this method is trajectory based, mechanistic analysis of the dynamics is straightforward. We also calculate semiclassical momentum distributions for double ionization following 25 fs and 795 nm pulses at 1.5 10$^{15}$ W/cm$^2$, in order to compare to the detailed experiments by Rudenko et al. For this more challenging task, full convergence is not achieved, but however major effects such as the finger-like structures in the momentum distribution are reproduced.

D1.00038 Strong-field control over the product branching ratios in molecular dissociation$^1$, BRANDON RIGSBEE, MOHAMMAD ZOHRAKI, UTUQ ABLIKIM, NICOLAI GUEVARA, KEVIN CARNES, ITZIK BEN-ITZHAK, BRETT ESRY, J. R. Macdonald Laboratory, Department of Physics, Kansas State University, Manhattan, Kansas 66506, USA — We present a theoretical and experimental study of strong-field control over the fragmentation channel by molecular dissociation by intense, single-color laser fields with emphasis on the effect of chirped pulses. In particular, the branching ratio between H+D$^+$ and H$^++$D from an HD$^+$ target is examined as a function of kinetic energy release for 790 nm pulses with intensities on the order of 10$^{14}$ W/cm$^2$ and pulse lengths ranging from 25 to 65 fs. Theoretical calculations based on numerical solutions of the time-dependent Schrödinger equation in the Born-Oppenheimer approximation are compared to measurements using a coincidence 3-D momentum imaging technique. Both demonstrate that control is indeed possible and depends, as expected, on details of the laser pulse such as its chirp.

1Supported by the Chemical Sciences, Geosciences, and Biosciences Division, Office of Basic Energy Sciences, Office of Science, U.S. Department of Energy.
Quantum resonances in selective rotational excitation of molecules with a sequence of ultrashort laser pulses\textsuperscript{1}. SERGEY ZHDANOVICH, CASEY BLOOMQUIST, The University of British Columbia, JOHANNES FLOSS, ILYA AVERBUKH, The Weizmann Institute of Science, JOHN HEBURN, VALERY MILNER, The University of British Columbia — The periodically kicked rotor is a paradigm system for studying classical and quantum chaos. In the quantum regime, the dynamics of the kicked rotor exhibit such phenomena as suppression of classical chaos, Anderson localization in angular momentum and quantum resonances in the accumulation of rotational energy. Even though these effects have been studied with ultracold atoms in optical fields and Rydberg atoms in microwave fields, they have never been observed in a real rotational system. In this work we study the effect of quantum resonance in the rotational excitation of a diatomic molecule. By using femtosecond pulse shaping and rotational state-resolved detection, we measure the rotational distribution of molecules interacting with a train of pulses. We show enhancement of population transfer from ground to excited rotational states at resonance, and demonstrate selective rotational excitation of two nitrogen isotopes. We utilize fractional quantum resonances for separating para- and ortho-nitrogen, paving the way to novel methods of coherent control of molecular rotation.

\textsuperscript{1}Supported by CFI, BCKDF, NSERC, ISF, DFG, Minerva Foundation

D1.00040 Molecular Ionization at High Intensities: Characterizing OPA Laser Pulses\textsuperscript{1} . COLLIN MCACY, University of Nebraska-Lincoln, RYAN KARNEMAA, Rose-Hulman Institute of Technology, SKYLER MARSH, Southeast Missouri State University, DAVID FOOTE, CORNELIS UITERWAAL, University of Nebraska-Lincoln — Ultrashort laser pulses have long been the primary instruments of probing and analyzing intense-field molecular dynamics on femtosecond timescales. In particular, processes involving resonance-enhanced multiphoton ionization (REMPI) have provided insight into ionization and dissociation dynamics. Typically the scope of REMPI is limited by the laser properties; namely, REMPI is limited by the transition energies accessible by an integer number of photons. However, the ability to tune the energies of these photons adds flexibility to the available resonances and, for longer wavelengths, makes tunneling the dominant ionization process. Optical parametric amplification (OPA) provides these changes, but the nonlinear processes required for OPA could have complicating effects on pulse duration and focusability, distorting beam quality and compromising experiments. We present the parametric amplification of 800-nm, 50-fs laser pulses in a TOPAS-C system; we use autocorrelation, power measurements, and knife-edging techniques to determine output pulse duration, intensity, and focal characteristics as a function of wavelength. We also report on the effects such changes will have on the practicality of various techniques requiring high-intensity processes.

\textsuperscript{1}This material is based upon work supported by the National Science Foundation under Grant No. PHY-0355235.

D1.00041 ATOMIC, MOLECULAR, AND CHARGED PARTICLE COLLISIONS I —

D1.00042 High Resolution X-ray Spectroscopy of Charge Exchange Collisions of Astrophysical Interest\textsuperscript{1} . J.I. DRAGANIC, C.C. HAVENER, C.R. VANE, Physics Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA, X. DEFAY, K. MORGAN, D. MCCAMMON, Department of Physics, University of Wisconsin, Madison, WI 53706, USA, M. FOGLE, Department of Physics, Auburn University, Auburn, AL 36849, USA — Soft X-ray emission following charge exchange (CX) by fully stripped and hydrogen-like ions of carbon, nitrogen, and oxygen on H, H\textsubscript{2} and He were measured in a collision energy range of 0.5 keV/u – 30.0 keV/u. CX experiments were performed using the ORNL Multicharged Ion Research Facility ion-atom merged-beams apparatus with a high resolution X-ray quantum calorimeter (XQC) from the University of Wisconsin. First recorded X-ray spectra were made with He and H\textsubscript{2} gases introduced into the beam line and with ion beams decelerated from a high voltage platform to simulate a range of solar wind ion velocities. Current results are compared with the previous experimental and theoretical studies, and presented along with the status of CX measurements with atomic hydrogen using a merged-beams technique.

\textsuperscript{1}Research sponsored by the NASA Solar & Heliospheric Physics Program NNH07ZDA001N, the Office of Fusion Energy Sciences and the Division of Chemical Sciences, Geosciences, and Biosciences, Office of Basic Energy Sciences, U.S. Department of Energy.

D1.00043 Progress in development of public three-body code\textsuperscript{1}. VLADIMIR ROUDNEV, MICHAEL CAVAGNERO, University of Kentucky — We report our progress in development of public software for fast and accurate quantum mechanical three-body calculations. This tool allows general users to perform bound state and low energy scattering calculations for general three-body below the break-up threshold. We describe the basics of the numerical scheme, the procedure of automatic grid construction and report results for elastic and reactive scattering in atom-dimer collisions.

\textsuperscript{1}Supported by NSF grant PHY-0903956.

D1.00044 Anisotropy induced Feshbach resonances in quantum dipolar gas of magnetic atoms\textsuperscript{2}. ALEXANDER PETROV, Temple University, EITE TIESINGA, NIST/JQI, SVETLANA KOTOCHIGOVA, Temple University — The best atoms to search for effects of anisotropy on collisions are submerged-shell atoms, which have an electronic configuration with an unfilled inner shell shielded by a closed outer shell. In particular, we are interested in the \textsuperscript{5}\textit{I}s ground-state rare-earth dysprosium (Dy) atom with total atomic angular momentum \textit{j} = 8 and a large magnetic moment of \textit{l} \textapprox 10\mu\textsubscript{B}, for which the 4\textit{F}\textsuperscript{14} electrons in the inner shell are aligned in such a way that the orbital moment is largely unquenched. As a result, Dy magnetic and electrostatic properties are highly anisotropic. Here we introduce a new coupled-channel model allowing us to calculate the anisotropy-induced magnetically-tunable Feshbach resonance spectrum of bosonic Dy atoms. The model treats the Zeeman interaction of the Dy atoms due to an external magnetic field and the magnetic dipole-dipole, (isotropic and anisotropic) electrostatic dispersion, and electric quadrupole-quadrupole interactions on equal footing. Our detailed quantum mechanical calculation describes a novel anisotropic nature of Feshbach resonances in interactions between magnetic Dy atoms and reveals a striking correlation between anisotropy in magnetic and electrostatic interactions and the Feshbach spectrum.

\textsuperscript{2}This work is supported by grants of the Air Force Office of Scientific Research, NSF PHY-1005453 and Army Research Office.

D1.00045 Study of collisional dynamics in highly excited Li\textsubscript{2}. MARK ROSENBERY, Siena College, RAMESH MARHATTA, BRIAN STEWART, Wesleyan University — Energy transfer during molecular collisions is a fundamental process in astronomy and chemistry. As Li\textsubscript{2} is a relatively simple molecule, it has been possible to model collisions of its low-lying excited state with ground state atoms for some years. We now intend to experimentally measure collisions involving much higher energy levels: studying the vibrational inelastic collisions and dissociation for molecules starting in the A (1\Sigma\textup{+}\textsubscript{g}, v = 45) states, and working towards studies of V-R coupling in the "shell" region of the E (3\Sigma\textup{+}\textsubscript{g}) state. To carry out these experiments, we are using a dual pulsed dye laser system. We have recently demonstrated that we can measure equivalent rate constants using either pulsed or cw excitation.

D1.00046 ABSTRACT WITHDRAWN —
D1.00047 Rotationally inelastic collisions of He and Ar with NaK: Experiment and theory\textsuperscript{1}, R.F. MALENDA, J. JONES, C. FAUST, K. RICHTER, C.M. WOLFE, A.P. HICKMAN, J. HUENNEKENS, Lehigh University, D. TALBI, F. GATTI, Universite Montpellier II — We are investigating collisions of the ground \((X^1\Sigma^+)\) and first excited \((A^1\Sigma^+)\) electronic states of NaK using both experimental and theoretical methods. Potential surfaces for HeNaK (fixed NaK bond length) are used for coupled channel calculations of cross sections for rotational energy transfer and also for collisional transfer of orientation and alignment. Additional calculations use the MCTDH wavepacket method. The measurements of the \(A\) state collisions involve a pump-probe excitation scheme using polarization labeling and laser-induced fluorescence spectroscopy. The pump excites a particular ro-vibrational level \((v, J)\) of the \(A\) state from the \(X\) state, and the probe laser is scanned over various transitions to the \(3\Pi_1\) state. In addition to strong direct transitions, weak satellite lines are observed that arise from collisionally-induced transitions from the \((v, J)\) level to \((v, J' = J + \Delta J)\). This method provides information about the cross sections for transfer of population and orientation for \(A\) state levels, and it can be adapted to transitions starting in the \(X\) state. For the \(A\) state we observe a strong \(\Delta J = \pm 1\) propensity for both He and Ar perturbers. Preliminary results for the \(X\) state do not show this propensity.

\textsuperscript{1}Work supported by the National Science Foundation.

D1.00048 Experimental Studies of High Lying Electronic State of NaCs\textsuperscript{1}, CARL FAUST, JOSHUA JONES, Lehigh University, SETH ASHMAN, University of Wisconsin - Madison, KARA RICHTER, BRETT MCGEEHAN, A.P. HICKMAN, JOHN HUENNEKENS, Lehigh University — We present new results from experimental studies of high-lying electronic states of the NaCs molecule that are currently underway in our laboratory. The optical-optical double resonance method is used to obtain Doppler-free excitation spectra for several excited states. Selected data from the \(5^3\Pi_0, 4^3\Pi_1\) and other high lying electronic states are used to obtain Rydberg-Klein-Rees (RKR) and Inverse Perturbation Approach (IPA) potential curves. Small oscillations in the other wall of the \(5^3\Pi_0\) potential suggest strong interactions with other electronic states. A modified version of Le Roy's BCONT program was used to simulate NaCs \(5^3\Pi_0 \rightarrow 1(a')\Sigma^+\) bound-free emission spectra. These simulations were used to fit the experimental spectra with a parameterized \(1(a')\Sigma^+\) repulsive wall and the \(5^3\Pi_0 \rightarrow 1(a')\Sigma^+\) transition dipole moment function, \(\mu(R)\). The fitted \(\mu(R)\) is in good agreement with the theoretical transition dipole moment function of Aymar and Dulieu [Mol.Phys. \textbf{105}, 1733 (2007)]. In related work, we have identified additional electronic states which we have tentatively assigned as the \(4^3\Pi_0\) and \(5^3\Pi_1\) (and possibly the \(5^3\Pi_2\)) electronic states of NaCs.

\textsuperscript{1}Work supported by the National Science Foundation.

D1.00049 Free-free transitions in the presence of laser fields and Debye potential at very low incident electron energies, ANAND BHATIA, NASA/Goddard Space Flight Center — We study the free-free transition in electron-helium ion in the ground state and embedded in a Debye potential in the presence of an external laser field at very low incident electron energies. The laser field is treated classically while the collision dynamics is treated quantum mechanically. The laser field is chosen as monochromatic, linearly polarized and homogeneous. The incident electron is considered to be dressed by the laser field in a nonperturbative manner by choosing Volkov wave function for it. The scattering wave function for the incident electron on the target embedded in a Debye potential is solved numerically by taking into account the effect of electron exchange. We calculate the laser-assisted differential and total cross sections for free-free transition for absorption/emission of a single photon or no photon exchange. The results will be presented at the conference.

D1.00050 Electron scattering from silicon\textsuperscript{1}, OLEG ZATSARINNY, KLAUS BARTSCHAT, Drake University, SERGEJ GEDEON, VLADIMIR LAZUR, ELIZABETH NAGY, Uzhgorod State University, Ukraine — The B-spline R-matrix method \cite{1} is used to study electron collisions with neutral silicon over an energy range from threshold to 100 eV. The multiconfiguration Hartree-Fock method with non-orthogonal orbitals is employed for an accurate representation of the target wave functions. The close-coupling expansion includes 34 bound states of neutral silicon derived from the \([\text{Ne}]3^2S^2p^2, 3^2S^1p^3, 3^1S^1p^4, 3^3S^1p^3, 3^3S^1p^5, 3^3S^1p^6, 3^1S^3p^4d\) and \(3^3S^1p^4d\) configurations, plus seven pseudostates to fully account for the dipole polarizability of the ground state and the lowest three excited states. Results are presented for transitions from the \(3^3S^1p^2\) ground state and the metastable \(3^3S^1p^2\) \(2D\) and \(3^3S^1p^2\) \(2S\) states. Both correlation and polarization effects are found to be important for accurate calculations. The sensitivity of the results was checked by comparing data obtained in different approximations. The current predictions represent an extensive set of electron scattering data for neutral silicon. The results are compared with those obtained earlier for e-C collisions \cite{2}.

\textsuperscript{1}Work supported, in part, by the United States National Science Foundation under PHY-0903818 and PHY-1068140, and by the TeraGrid/XSEDE allocation TG-PHY090031.

D1.00051 B-Spline R-Matrix with Pseudo-States Treatment of Electron Collisions with Neon\textsuperscript{1}, OLEG ZATSARINNY, KLAUS BARTSCHAT, Drake University — We have further developed the B-Spline R-matrix (BSR) code \cite{1} to allow for a large number of pseudo-states in the close-coupling expansion. In the present work, the BSRMPS approach \cite{2} was employed to perform semi-relativistic (Breit-Pauli) close-coupling calculations for elastic scattering, excitation, and ionization of neon from both the ground state and the metastable excited states. Coupling to the ionization continuum through the pseudo-states is important for low-energy elastic scattering (to represent polarizability effects), for excitation in the “intermediate” energy regime of about 1-3 times the ionization potential, and to allow for the calculation of ionization processes by transforming the results obtained for excitation of the positive-energy pseudo-states. The current results represent a significant extension of our earlier near-threshold work \cite{3} and previous RMPS calculations \cite{4,5}.

\textsuperscript{1}Work supported by the United States National Science Foundation under PHY-0903818 and PHY-1068140, and by the TeraGrid/XSEDE allocation TG-PHY090031.
**D1.00052** Electron-impact excitation of CI$^+$, A.M. SOSSAH, S.S. TAYAL, Clark Atlanta University — We present calculation results for electron-impact excitation of CI$^+$ ions. The collision strengths are calculated in the close-coupling approximation using the B-spline Breit-Pauli R-matrix method. The multi-configuration Hartree-Fock method with term-dependent non-orthogonal orbitals is employed for an accurate description of the target wave functions. The 68 fine-structure levels belonging to the 32 LS states of 3s$^2$3p$^3$, 3s$^2$3p$^3$3d, 3s$^2$3p$^3$4s and 3s$^2$3p$^3$4p configurations are included in the close-coupling approximation; this leads to 2278 possible fine-structure transitions. The effective collision strengths are obtained by averaging the electron collision strengths over a Maxwellian distribution of velocities, and these are tabulated for all fine-structure transitions at electron temperatures in the range 5000 to 20000 K. Our results are compared with previous theoretical results and available experimental data. This work is supported by NASA grant NNG09AB65G from the Planetary Atmospheres Program.

**D1.00053** Electron-impact ionization of Li$_2$, SHAHIN ABDEL-NABY, M.S. PINDZOLA, J.A. LUDLOW, F. ROBICHEAUX, Auburn University, J. COLGAN, Los Alamos National Laboratory — Electron-impact ionization cross sections are calculated for Li$_2$. A two active electron time-dependent close-coupling method is used to calculate cross sections for Li$_2$ at the equilibrium internuclear distance for incident energies of 10 eV, 15 eV, and 20 eV. The nonperturbative close-coupling cross sections are found to be lower than perturbative distorted-wave cross sections due to electron correlation effects between the two outgoing continuum electrons.

1 This work was supported in part by grants from the US Department of Energy. Computational work was carried out at NERSC in Oakland, California.

**D1.00054** Momentum Imaging of Dissociative Electron Attachment to Molecules, ALI MORADMAND, JOSHUA WILLIAMS, ALLEN LANDERS, MIKE FOGLE, Auburn University — Dissociative electron attachment (DEA) to diatomic and polyatomic molecules, including O$_2$, C$_2$H$_2$, and CO$_2$, is studied using a COLTRIMS apparatus which is capable of imaging 3D dissociation dynamics upon impact from a low energy (~100eV) electron. A pulsed electric field is used to extract and distinguish ion fragments in a time-of-flight mass spectrometer, from which a complete picture of the reaction dynamics may be constructed. Through the axial recoil approximation, dependence of the attachment probability on a molecule’s orientation with respect to the incoming electron’s momentum is revealed.

**D1.00055** Metastable Decay of Molecular Ions, PENGQIAN WANG, Western Illinois University — Metastable dissociation of singly and multiply ionized molecules has been observed in two-observer coincidence mass spectra of molecules caused by electron impact dissociative ionization. These molecules include ethane, propane, butane, carbonyl sulphide and isocyanic acid. The decay of the molecular ions occurs either in the ion acceleration region or in the drift tube of a Wiley-McLaren type mass spectrometer, which exhibits two distinctly featured traces on the coincidence mass spectrum if the lifetime of the molecule is much longer than the time-of-flight of the ions. These traces generally start from a coincidence island, which indicates the species of the daughter ions, and ends at a point on the diagonal of the spectrum, which indicates the species of the parent ion. The intensity distribution and the geometric properties of the decay traces can be used to retrieve valuable information on the decay lifetime and dissociation dynamics of the molecular ions. Some new decay channels have been discovered. Asymmetric charge distribution and orientation of the molecular ions in the mass spectrometer has also been observed. Project supported by the WIU-URC grant.

**D1.00056** Dissociative recombination of HCl$^{+}$, ASA LARSON, Dept. of Physics, Stockholm University, SAMANTHA FONSECA DOS SANTOS, ANN E. OREL, Dept. of Chemical Engineering and Materials Science, University of California, Davis — Recently, the molecular ion HCl$^{+}$ has been observed in the interstellar medium. There is little information available about the cross sections for creation and destruction of this ion. Therefore, we have begun calculations to predict the dissociative recombination cross section and the final state distribution of atomic states produced in the dissociation. The relevant electronic states are calculated ab initio by combining electron scattering calculations using complex Kohn variational method to obtain resonance positions and autoionization widths and multi-reference configuration interaction calculations to construct the ion and Rydberg states. The direct dissociation recombination cross section is obtained by using wave packets propagating on the resonant states.

1 This work was supported by the National Science Foundation, Grant No. PHY-08-55092 and the Swedish research council (VR).

**D1.00057** Theory of dissociative recombination of highly-symmetric polyatomic ions, VIAITCHESLAV KOKOULINE, Department of Physics, University of Central Florida, NICOLAS DOUGUET, ANN E. OREL, Department of CHMS, University of California at Davis, CHRIS H. GREENE, Department of Physics and JILA, University of Colorado at Boulder — A general first-principles theory of dissociative recombination is developed for highly-symmetric molecular ions and applied to H$_2$O$^{+}$ and CH$_4$$^{+}$, which play an important role in astrophysical, combustion, and laboratory plasma environments. The theoretical cross-sections obtained for the dissociative recombination of the two ions are in good agreement with existing experimental data from storage ring experiments.

2 We would like to thank Ioan Schneider for attracting our attention to study H$_2$O$^{+}$ and CH$_4$$^{+}$. This work has been supported by the NSF and DOE. VK also acknowledges support from the RTRA network Triangle de la Physique.

**D1.00058** Rotating wall compression of positron swarm in a harmonic potential: a Monte Carlo simulation, SRJDAN MARJANOVIC, ANA BANKOVIC, MILOVAN SUVAKOV, Institute of Physics Belgrade, University of Belgrade, Pрегревица 118, 11080 Zemun, Serbia, C. ALED ISAAC, DIRK PETER VAN DER WERF, MICHAEL CHARLTON, Department of Physics, College of Science, Swansea University, Singleton Park, Swansea SA2 8PP, United Kingdom, ZORAN LJ. PETROVIC, Institute of Physics Belgrade, University of Belgrade, Pregrevica 118, 11080 Zemun, Serbia — Several experiments have demonstrated successful application of rotating wall technique for compressing positron beams in a single particle regime. While the basic mechanism of compression is understood, the role of the cooling gases which have to be used is poorly explained. Thus, we have simulated behavior of a swarm of particles (electrons or positrons) in an antisymmetric dipole rotating field inside a buffer gas trap. We have used our existing Monte Carlo code for the simulation, as the single particle conditions are inherently assumed. Varying mixtures of CF$_4$ and N$_2$ are used as the buffer gas in order to mimic the operating conditions of Surko trap, and to pinpoint the collisions responsible for compression. For a given parameter range, the simulation shows significant compression and axialization of positron swarm. We have investigated the change of swarm behavior by varying the applied rotating wall potential and frequency, strength of axial magnetic field, and background gas composition and pressure. The results show fast initial heating of the swarm, and subsequent cooling to the thermal temperature, as the radius of the cloud compresses, demonstrating that it is possible to compress the beam of charged particles in a single particle regime.

**D1.00059** Low energy positron beam studies, JIM WILLIAMS, University of Western Australia, VALDIMIR PETROV, St. Petersburg State Polytechnical University, SUDARSHAN KATHI, SERGEY SAMARIN, PAUL GIAGLIARDO, University of Western Australia, ALEX WEISS, SUARABH MUKHERJEE, University of Texas at Arlington — Measurements of positrons interacting with atoms and surfaces indicate surface structure and scattering dynamics. The positron beam has an energy range from about 1 to 900 eV, an expected polarization of about 20% and intensity of 1000 counts/sec in a 10 mm radius on a microchannel plate detector used in retarding potential mode. A W(100) single crystal at 10$^{-10}$ mbar supports the growth of Fe thin films. Results indicate the elastic and inelastic scattering of positrons, generation of secondary electrons, re-emission of thermalized positrons normal to different surfaces and various scattering mechanisms.
D1.00060 Radiative double electron capture (RDEC) in collisions of bare fluorine ions with carbon foils, T. ELKAFRAWY, J.A. TANIS, Department of Physics, Western Michigan University, A. SIMON, Michigan State University, NSCL, A. WARCZAK, Institute of Physics, Jagiellonian University, Krakow — Radiative double electron capture (RDEC) is a charge exchange process involving the capture of two target electrons into a bound state of the projectile simultaneously with the emission of a single photon. RDEC is the time reversed process of double photoionization if the target electrons are loosely bound. This approach provides us with a clean tool to explore the problems involved with electron-electron correlations and a proper description of a two-electron-continuum wave function in various atomic systems. In this work, we investigate both radiative electron capture (REC) and RDEC in collisions of 42 MeV singly- and doubly-charge changed fluorine ions with carbon targets. The experiment was performed at the tandem Van de Graaff accelerator of Western Michigan University in which emitted x rays were measured at 90° to the beam line in coincidence with projectile charge-changing of bare and H-like fluorine. The first evidence to see the RDEC process in O\(^{\pm}\) + C collisions was the motivation to conduct the current work for the sake of the comparison between both observations and with recent theoretical calculations.


D1.00061 Importance of post collision interactions for charge transfer process, UTTAM CHOWDHURY, Missouri University of Science and Technology, ALLISON HARRIS, Henderson State University, JERRY PEACHER, DON MADISON, Missouri University of Science and Technology — Recently experimental fully differential cross sections (FDCS) have been reported for double capture, single capture and transfer excitation in proton helium collisions. In case of double capture, the proton captures both of the electrons from helium and leaves the collision as a H- ion. For single capture, the proton captures one electron from helium and leaves the other electron in the ground state. Transfer excitation is similar to single capture except the target is excited to an excited state. Recently experiments performed for proton energies ranging from 25keV to 300keV. We introduce here a theoretical model for charge transfer processes which is fully quantum mechanical and takes all post collision interactions (PCI) between the particles into account exactly. Numerically, this requires a full nine-dimensional integral which is computationally expensive. The theoretical results will be compared with absolute experimental measurements.

3. Work supported by the NSF under grant 1068237 and the NSF XSEDE.

D1.00062 QUANTUM OPTICS, MATTER OPTICS, AND COHERENT CONTROL I —

D1.00063 Robust and Efficient Population Transfer in Ultracold Rubidium Using A Single Linearly Chirped Laser Pulse With a Novel Pulse Envelope, THOMAS COLLINS, SVETLANA MALINOVSKAYA, Stevens Institute of Technology — The ability to manipulate the state of a quantum system is the at very heart of the field of quantum control. As quantum control is an essential aspect of the emerging field of quantum computing, it is necessary to find techniques for manipulating quantum systems that are both robust and efficient to implement industrially. In this work the population dynamics of the valence electron of Rubidium, interacting with a single linearly chirped laser pulse, are studied. The pulse envelope is constructed from overlapping Gaussian waveforms and is described analytically by the formula:

\[ E_0 \sum_{n=0}^{\infty} e^{-\frac{(\gamma n)^2}{2 \sigma^2}} \delta \]

with the parameter \( \sigma \) being the separation in time between each peak with the oscillating electric field is phase locked to the central peak. The response of the quantum yield obtained at the end of the pulse to changes in the parameters of the oscillating electric field and pulse envelope are studied. For certain values of these parameters, achievement of a transfer of over 99% of the population to a desired quantum state within the hyperfine structure of the 5S\(^1\) state via adiabatic passage using beam intensities which are on the order of 100W/cm\(^2\) is demonstrated. Results are robust in the adiabatic regime.

3. This research is partially supported by the National Science Foundation under Grant No. PHY-0855391.

D1.00064 Single chirped pulse control of hyperfine states population in Rb atom in the framework of the four-level system, VLADISLAV ZAKHAROV, SVETLANA MALINOVSKAYA, Stevens Institute of Technology — Electron population dynamics within the hyperfine structure in the Rb atom induced by a single ns pulse is theoretically investigated. The aim is to develop a methodology of the implementation of linearly chirped laser pulses for the desired excitations in the Rb atoms resulting in the creation of predetermined non-equilibrium states. A semi-classical model of laser pulse interaction with a four-level system representing the hyperfine energy levels of the Rb atom involved into dynamics has been developed. The equations for the probability amplitudes as a function of the field parameters. The dependence of the quantum yield on the pulse duration, the linear chirp parameter and the Rabi frequency was studied to reveal the conditions for the entire population transfer to the upper hyperfine state of the 5S\(^1\)/2 electronic level. The results may provide a robust tool for quantum operations in the alkali atoms.

D1.00065 Image based adaptive femtosecond control of ethylene fragmentation, E. WELLS, C. RALLIS, T. BURWITZ, P. ANDREWS, A. VOZNYUK, Department of Physics, Augustana College. Sioux Falls, SD 57197 USA, M. ZOHRAI, BETHANY JOCHIM, U. ABLIKIM, K.D. CARNES, M.F. KLING, J.R. Macdonald Laboratory, Kansas State University, Manhattan KS 66506 USA — Using an adaptive femtosecond control scheme, ethylene is ionized by a shaped ultrafast laser pulse, leading to isomerization to the ethyleneide (HC-CH\(_3\))\(^{1+}\) configuration, from which CH\(_3\)\(^+\) fragments are generated. Feedback for the control process is obtained by rapidly inverting velocity map images of the CH\(_3\)\(^+\) and competing CH\(_2\)\(^+\) fragments, allowing identification of dissociation channels and subsequent control of the CH\(_3\)\(^+\)/CH\(_2\)\(^+\) ratio. Additionally, we have identified the C\(_2\)H\(_2\)\(^+\) \( \rightarrow \) C\(_2\)H\(_3\)\(^+\) \+ H and C\(_2\)H\(_2\)\(^+\) \( \rightarrow \) C\(_2\)H\(_2\)\(^+\) \+ H\(_2\) channels as creating ion images with rich structure that offer possible routes to investigate control via conical intersections on the C\(_2\)H\(_3\)\(^+\) potential energy surface.

3. Augustana College personnel are supported by NSF grants PHY-0969687 and EPS-0903804 while JRML is supported by the Chemical Sciences, Geosciences, and Biosciences Division, Office of Basic Energy Science, Office of Science, US Department of Energy.
D1.00066 Electromagnetically induced transparency and absorption in warm Rb vapor via the Hanle effect: Analysis of observed spectra†, JASON BARKELOO, JOHN CAMENISCH, WILLIAM KONYK, BRADLEY WORTH, AMANDA DAY, PERRY RICE, SAMIR BALI, Department of Physics, Miami University — We have observed electromagnetically induced transparency (EIT) and electromagnetically induced absorption (EIA) in room temperature Rubidium vapor, by coherent population trapping on the Zeeman substates formed by a magnetic field co-linear with a laser beam passing through the vapor. We have observed EIA on $F_g = 3 \rightarrow F'$ transitions in $^{85}$Rb and on $F_g = 2 \rightarrow F'$ transitions in $^{87}$Rb. We have observed with good signal-to-noise ratio EIT on $F_g = 2 \rightarrow F'$ transitions in $^{85}$Rb and, for the first time, on $F_g = 1 \rightarrow F'$ transitions in $^{87}$Rb. However, certain unexpected features are revealed in the observed spectra, the origins for which remain unclear. We report on our progress towards modeling and understanding the observed EIT and EIA spectra.

†We gratefully acknowledge financial support from Petroleum Research Fund and Miami University.

D1.00067 Superluminal squeezed light propagation with Rb atoms, TRAVIS HORROM, GLEB ROMANOV, IRINA NOVIKOVA, EUGENIY MIKHAILOV, College of William and Mary, COLLEGE OF WILLIAM AND MARY QUANTUM OPTICS LAB TEAM — We present an all atomic method for the generation and manipulation of broadband squeezed states of light ranging in frequency from a few hundred Hz to several MHz and matching an atomic transition of Rb atoms. Our squeezer is based on the polarization self-rotation (PSR) effect in an atomic medium. We have developed a method allowing us to cast an arbitrary temporal pulse shape of the squeezed state by applying a longitudinal magnetic field to the squeezing Rb cell. Such a modulated squeezed state can then serve as a quantum probe to an atomic ensemble of hot Rb vapor. We show that under certain conditions, the squeezed light shows a superluminal propagation speed through the Rb vapor. Also, the application of an additional optical field to the atomic ensemble allows us to control and selectively filter the squeezed state of light. These techniques are of potential interest for precision metrology and the quantum information community.

D1.00068 Controlling emission of nitrogen-vacancy centers in diamond with nanoscale photonic interfaces, NATHALIE DE LEON, BRENDAH SHIELDS, YIWEN CHU, Harvard University Department of Physics, BIRGIT HAUSMANN, MICHAEL BUREK, Harvard University School of Engineering and Applied Sciences, HONGKUN PARK, Harvard University Department of Chemistry and Chemical Biology, MARCO LONCAR, Harvard University School of Engineering and Applied Sciences, MIKHAIL LUKIN, Harvard University Department of Physics — Nitrogen-vacancy (NV) centers are a promising candidate for quantum information processing. They act as artificial atoms in the solid state that can be addressed optically, exhibit spin-dependent fluorescence, and can have transform-limited linewidths at the zero phonon line (ZPL). However, most (>50%) of the emission is into a broad, incoherent phonon side band, limiting quantum applications. We will present recent progress toward coupling NV centers in bulk diamond to photonic crystals and waveguides, with the goal of directing emission into the ZPL and realizing the strong coupling regime for applications such as entanglement of distant NV centers and single photon transistors.

D1.00069 3D Raman sideband cooling of single atoms in an optical tweezer trap, JEFF THOMPSON, TOBIAS TIECKE, Department of Physics, Harvard University, VLADAN VULETIC, Department of Physics, MIT-Harvard Center for Ultracold Atoms and Research Laboratory of Electronics, Massachusetts Institute of Technology, MIKHAIL LUKIN, Department of Physics, Harvard University — We have cooled a single atom in an optical tweezer trap very close to its three-dimensional ground state. An atom loaded with an initial temperature of around 110 uK has radial and axial occupation numbers of $n_r = 25$ and $n_a = 170$; after cooling, we achieve final occupation numbers of $n_r < 0.1$ and $n_a < 7.5$. The principal technical challenge we encountered was effective magnetic field gradients around the tweezer focus, which we will discuss in some detail. Additionally, we will present ongoing work on two fronts: using the tightly localized atom to sense optical fields on the nanometer-scale, and bringing the atom close to nanoscale optical waveguides and can interact with the light field in strong atom-photon interactions.

D1.00070 Progress towards building lattice atom interferometer using $^7$Li, GEENA KIM, PAUL HAMILTON, UC Berkeley, HOLGER MUELLER GROUP TEAM — We are building a single atom interferometer using $^7$Li atoms for the ultimate goal to test the universality of free fall. To deal with light mass of lithium and its large recoil velocity, we will develop a new technique using an optical lattice. The lattice will act as a waveguide to prevent atom losses due to the high thermal velocity of Li, and as large momentum transfer beam splitters in analogy to the Bloch-Bragg-Bloch beam splitters already developed by us [2,3]. We discuss investigations of novel all-optical cooling of lithium using degenerate Raman sideband cooling as well as recent progress towards a demonstration of the first atom interferometer using $^7$Li.


D1.00071 Atom Interferometry: A Matter Wave Clock and a Measurement of $\alpha$, BRIAN ESTEY, SHAU-YU LAN, PEI-CHEN KUAN, MICHAEL HOHENSEE, Department of Physics, University of California, Berkeley, PHILIPP HASLINGER, VQC, Faculty of Physics, University of Vienna, Boltzmanngasse, PAULI KEHAYIAS, DAMON ENGLISH, HOLGER MÜLLER, Department of Physics, University of California, Berkeley — Developments in large-momentum transfer beam splitters (eg. Bragg diffraction) and conjugate Ramsey-Bordé interferometers have enabled atom interferometers with unparalleled size and sensitivity. The atomic wave packet separation is large enough that the Coriolis force due to the earth’s rotation reduces interferometer contrast. We compensate for this effect using a tip-tilt mirror, improving our contrast by up to a factor of 3.5, allowing pulse separations of up to 250 ms with 10kHz beam splitters. This interferometer can be used to make a precise measurement of the recoil frequency ($\nu \equiv h/m$) and thus the fine structure constant. The interferometer also gives us indirect access to the Compton frequency ($\nu_{CM} \equiv mc^2/h$) oscillations of the matter wave, since $h/m$ is simply $c^2/\nu_{CM}$. Using an optical frequency comb we have demonstrated the interferometer’s laser frequency to a multiple of a cesium atom’s recoil frequency. This self-referenced interferometer thus locks a local oscillator to a specified fraction of the cesium Compton frequency, with a fractional stability of 2 ppb over several hours. This has potential application in redefining the kilogram in terms of the second. We also present a preliminary measurement of the fine structure constant.

D1.00072 Condensate Interferometry in a Magnetic Guide†, R.A. HORNE, R.H. LEONARD, C.A. SACKETT, University of Virginia — We present recent progress on experiments on atom interferometry using Bose-Einstein condensates confined in a magnetic guide. Several sources of decoherence can be avoided by using a harmonic trap potential to control the motion of the the atoms, and common-mode noise sources such as vibrations can be controlled using simultaneous dual interferometers in the same trap. Important limitations that remain include anharmonicity in the trap potential and residual motion of the condensate in the trap. We will also describe a new apparatus featuring a cylindrically symmetric potential that is optimized for gyroscopic measurements.

†Supported by the NSF

D1.00073 ABSTRACT WITHDRAWN
D1.00074 Generation of single frequency blue light by highly efficient harmonic generation of IR laser diodes in resonance build-up cavities using nonlinear crystals, ALI KHADEMIAN, KOUSTUBH DANEKAR, NAFISEH AFLAKIAN, DAVID SHINER, University of North Texas — Blue and UV lasers have a wide variety of applications, including atomic spectroscopy. We are particularly interested in 486 nm and 243 nm for hydrogen spectroscopy. Blue and UV laser diodes are at the early stages of development. At this time, harmonic generations (HG) is a viable technique to produce blue and UV light with well developed fiber coupled IR laser diodes. We recently reported a polarization maintaining (PM) fiber to fiber conversion efficiency of 71 percent overall. We used a PPKTP (Periodically Poled Potassium Titanyl Phosphate) crystal in an external build-up cavity. The 600 mW of blue at 486 nm was generated from second HG of a 972 nm PM fiber coupled laser diode [1]. PPKTP presents blue absorption (BA) and blue light induced IR absorption (BLIIIRA) which cause thermal instability and inefficiency in the buildup cavity. Another crystal, PPSLT (Periodically Poled Lithium Tantalite) promises less BA and less BLIIIRA. Our latest results for producing 486 nm using PPSLT and comparison with PPKTP will be presented.


D1.00075 Microscopic and Macroscopic Descriptions of Nonlinear Electromagnetic Interactions in Atomic Ensembles1, VERNE JACOBS, Naval Research Laboratory — Microscopic and macroscopic descriptions of nonlinear electromagnetic interactions relevant to resonant pump-probe phenomena in quantized many-electron systems are formulated within the framework of a general reduced-density-matrix approach. Time-domain (equation-of-motion) and frequency-domain (resolvent-operator) formulations are developed in a unified and self-consistent manner. A semiclassical perturbation treatment of the electromagnetic interaction is adopted, in which the electromagnetic field is described as a classical field satisfying either the microscopic form or the macroscopic form of the Maxwell equations. A quantized-field approach is essential for a fully self-consistent quantum-mechanical formulation. Compact Liouville-space operator expressions are obtained for the general (n'th order) non-linear electromagnetic-response tensors for moving atomic systems. Environmental interactions can be treated in terms of the Liouville-space self-energy operator.

1Work supported by the Office of Naval Research.

D1.00076 Quantum interference of single photons from two remote nitrogen-vacancy centers in diamond, MICHAEL GOLDMAN, ALP SIPAHIGIL, EMRE TOGAN, YIWEN CHU, Harvard University, Department of Physics, MARK MARKHAM, DANIEL TWITCHEN, Element Six Ltd, ALEXANDER ZIBROV, ALEXANDER KUBANEK, MIKHAIL LUKIN, Harvard University, Department of Physics — The interference of two identical photons impinging on a beam splitter leads to perfect photon coalescence where both photons leave through the same output port. This effect, known as Hong-Ou-Mandel (HOM) interference, can be used to characterize the properties of quantum emitters with high accuracy. This is a particularly useful tool for quantum emitters embedded in a solid state matrix because their internal properties, unlike those of atoms in free space, differ substantially from emitter to emitter due to strong interactions with the environment. HOM interference can also be used to generate optically mediated entanglement between two remote quantum emitters, a crucial step toward the development of long-distance quantum communication and scalable quantum computation architectures. Here, we demonstrate this interference effect with single photons emitted from two single Nitrogen-Vacancy (NV) centers in diamond samples that are spatially separated by 2 meters [1]. The detuning of the photons can be tuned by applying a DC electric field to one NV center. We discuss current efforts toward optical entanglement of the two NV centers.


D1.00077 Discrimination of one and two-photon effects in electromagnetically induced transparency for ladder-type three-level atoms, EUN HYUN CHA, TAEK JEONG, HEUNG-ROYUL NOH, Chonnam National University, HAN SEB MOON, Pusan National University — We present a theoretical study of complete discrimination of the effects of one-photon, two-photon, and their combination in electromagnetically induced transparency for a ladder-type three-level noncycling (or cycling) atomic system. By considering the interaction routes of the coupling and probe photons, we are able to completely discriminate the pure one-photon and pure two-photon effects. We show that the narrow EIT spectrum results from the pure two-photon effect, whereas the relatively broad spectrum results from the terms of pure one-photon and combination effects.

D1.00078 Control of Spectrally-Manifested Decoherence in Giant Rabi Sidebands1, DMITRI A. ROMANOV, Department of Physics and Center for Advanced Photonics Research, GEORGE HECK, ALEX FILIN, ROBERT J. LEVIS, Department of Chemistry and Center for Advanced Photonics Research, Temple University, Philadelphia, PA 19122 — We study the broadband Rabi oscillations supported by excited states of oxygen atoms in a laser-generated microplasma. The dynamic Rabi sidebands show characteristic fringe patterns of spatial-spectral interference. The variable contrast of these patterns is determined by decoherence phenomena in the nonequilibrium underdense microplasma channel, with corresponding decoherence times in the range of 750 fs to 3 ps. We have determined the decoherence rate as a function of the pump pulse intensity and the pump-probe delay time. The rate increases with the pump laser intensity and decreases with the delay, in good agreement with model calculations, revealing that electron scattering dominates the dynamics for the subnanosecond relaxation processes. The results provide insight into both the behavior of the transient effective two-state systems and the evolution of the characteristics of the laser-generated microplasma.

1We gratefully acknowledge financial support through the AFOSR MURI grant FA9550 10-1-0561.

D1.00079 QUANTUM INFORMATION I —
D1.00081 Quantum information processing between different atomic ions, Xiang Zhang, Bo Zheng, Junhua Zhang, Mark Um, Shuoming An, Tianji Zhao, Luming Duan, Kihwan Kim, Center for Quantum Information and Institute for Interdisciplinary Information Science, Tsinghua University, Beijing 100084 — There is increasing interest in utilizing and combining the advantages of different quantum systems. Here, we discuss the experimental generation of entanglement between the quantum states of different atomic ions through the Coulomb interaction at the same linear radio-frequency trap. This scheme would be extended to implement the teleportation of quantum information from one kind of atom to another. Moreover, the hybrid system of trapped ions is expected to play an essential role in the realization of a large quantum system, where a quantum state of one species is used for quantum operation and that of the other is for the cooling and stabilization of the whole ion chain. Finally, we will report the experimental progress on building the hybrid trapped ion system.

D1.00082 Improved ion addressing in surface electrode traps using compensating sequences, J. True Merrill, Georgia Institute of Technology, S. Charles Doret, Georgia Tech Research Institute, Kenneth Brown, Georgia Institute of Technology, Alexia Harter, Georgia Tech Research Institute — Several proposed quantum processor architectures require precise control over the intensity, duration, and spatial alignment of laser pulses. In particular, single-ion laser addressing in quantum registers composed of tightly-spaced ion chains is sensitive to errors introduced by pointing instabilities and by the finite beam waist. Compensating pulse sequences may relax these precision requirements by producing accurate gates in the presence of unknown systematic errors. Here we report on experimental progress in the suppression of systematic errors in the control of $^{40}\text{Ca}^+$ ions in a microfabricated surface electrode trap. Further, we discuss other systems where compensating sequences may be used to produce accurate gates in the presence of control errors.

D1.00083 2D Holographic optical lattices for single atoms manipulation, Lucas Beguin, Aline Verner, Thierry Lahaye, Antoine Browaeys, Laboratoire Charles Fabry — Two-dimensional lattices of single atoms are a promising environment allowing fine control of the atomic interactions in a mesoscopic ensemble. We propose an experiment to study the long range dipole-dipole interactions in the system working in the Rydberg blockade regime. The versatility of holographically generated 2D arrays of single atoms should allow us to achieve arbitrary geometries as well as site-to-site addressability, thus enabling the tunability of the interactions within the system.

D1.00084 Spectroscopy and Thermometry of Drumhead Modes in a Mesoscopic Trapped-Ion Crystal using Entanglement, Brian Sawyer, Joseph Britton, NIST-Boulder, CO, Adam Keith, NC, Joseph Wang, James Freericks, Georgetown University, Hermann Uys, CSIR, South Africa, Michael Biercuk, University of Sydney, John Bollinger, NIST-Boulder, CO — Studies of quantum mechanics at intermediate scales between microscopic and mesoscopic regimes have recently focused on the observation of quantum coherent phenomena in optomechanical systems. We demonstrate spectroscopy and thermometry of individual motional modes in a mesoscopic 2D ion array using entanglement-induced decoherence as a method of transduction. The system is a ~400 μm-diameter planar crystal of several hundred $^{9}$Be$^+$ ions exhibiting complex drumhead modes in the confining potential of a Penning trap. Exploiting precise control over the $^{9}\text{Be}^+$ valence electron spins, we apply a homogeneous spin-dependent optical dipole force to excite arbitrary transverse modes with an effective wavelength approaching the interparticle spacing (~20 μm). Center-of-mass displacements of ~120 pm are detected via entanglement of spin and motional degrees of freedom.

D1.00085 Quantum entanglement in helium-like ions, Y.-C. Lin, Y.K. Ho, Institute of Atomic and Molecular Sciences — Recently, there have been considerable interests to investigate quantum entanglement in two-electron atoms $[1-3]$. Here we investigate quantum entanglement for the ground and excited states of helium-like ions using correlated wave functions, concentrating on the particle-particle entanglement coming from the continuum spatial degrees of freedom. We use the two-electron wave functions constructed by employing $B$-spline basis to calculate the linear entropy of the reduced density matrix $L = 1 - Tr_A (\rho_A^2)$ as a measure of the spatial entanglement. Here $\rho_A = Tr_B (|\psi\rangle_A \langle \psi|)$ is the one-electron reduced density matrix obtained after tracing the two-electron density matrix over the degrees of freedom of the other electron. We have investigated the spatial entanglement for the helium-like systems with $Z=1$ to $Z=10$. For the helium atoms ($Z=2$), we have calculated the linear entropy for the ground state and the $1s1s^1S^+$ ($n=2$-10) excited states. Results are compared with other calculations $[1-3]$.

D1.00086 Ion traps for quantum information and simulation at ETH, Joseba Alonso, Ludwig Declercq, Ben Keitch, Daniel Kienzler, Florian Leupold, Frieder Lindenberg, Hsiang-Yu Lo, Jonathan Home, ETH Zürich — We are developing two new experimental setups for quantum information processing, simulation and state engineering with trapped atomic ions. The systems are designed to simultaneously trap both beryllium and calcium ions. The first system comprises a segmented linear Paul trap which will be run at room temperature. The second consists of a micro-fabricated surface trap which will operate at 4 Kelvin.

D1.00087 Using optical pulse shaping to entangle individual ions in a chain by coupling to multiple motional modes, TaeYoung Choi, T.A. Manning, S. Debnath, B. Fields, Chris Monroe, JQI and Physics Department, University of Maryland, College Park, MD 20742 — We present progress in an anharmonic linear trap that produces a uniformly-spaced chain of $^{171}\text{Yb}^+$ ions that allows for individual optical addressing. When 355 nm laser beams are directed to the target ions, Raman transitions can be driven to couple ion qubit states through their collective transverse motional modes $[1]$. By optimizing the parameters of the applied laser pulse sequences, simultaneous coupling to multiple modes of motion may allow for high gate fidelity while increasing the gate speed $[2]$. Here, we show simulations that optimize the intensities, duration, and detuning of the laser pulses as well as our preliminary results for implementing this scheme.


3This work is supported by grants from the U.S. Army Research Office with funding from the DARPA OLE program, IARPA, and the MURI program; the NSF PIF program; the NSF Physics Frontier Center at JQI; and the European Commission AQUTE program.
D1.00088 BEC magnetometry as a probe of hybrid quantum systems1, COLLIN REYNOLDS, CHANDLER KEMP, ELI FOX, KELVIN BLASER, MUKUND VENGALATTORE, Cornell University — We describe our progress towards realization of a hybrid quantum system consisting of a Bose Condensate magnetically coupled to a micromechanical oscillator. Due to the presence of a magnetic domain on the oscillator, the micromotion of the oscillator results in a periodically varying Zeeman shift that we measure using non-destructive imaging [1]. We estimate the sensitivity of the position readout to be comparable to the zero-point motion of the oscillator. We also outline prospects of achieving the strong-coupling limit of this BEC-membrane system to enable sympathetic cooling and the creation of non-classical states of this mechanical device [2]. In order to achieve this strong-coupling limit, we are investigating both cavity-enhanced schemes as well as coupling the BEC to a graphene membrane whose mass is comparable to that of the atomic gas.


1This work was funded by the DARPA QuASAR program through a grant from the ARO.

D1.00089 COLD ATOMS, MOLECULES, AND PLASMAS I —

D1.00090 Electrically guided continuous supersonic beams of polar molecules from a cryogenic buffer-gas source, XING WU, CHRISTIAN SOMMER, SOTIR CHERVENKOV, ANDREAS ROHLFES, MARTIN ZEPPENFELD, LAURENS VAN BUUREN, GERHARD REMPE, Max-Planck-Institut für Quantenoptik — In order to obtain dense samples of internally and translationally cold polar molecules, we use the method of buffer-gas cooling [1], combined with supersonic expansion. We have demonstrated that when the cryogenic buffer-gas cell is operated in a supersonic regime, molecular fluxes are hydrodynamically enhanced by up to two orders of magnitude. Meanwhile, the translational velocity profile of the output molecular beam is cooled to beyond Mach number 6 via supersonic expansion. Due to the cryogenic cell temperature, the forward velocity of the supersonic molecular beam is below 190 m/s. The low-field-seeking molecules in the so-produced continuous supersonic beam are selected via quadrupole electric guiding [2] and transferred to further experiments. Such high-flux guided continuous supersonic beams from a cryogenic reservoir provide a promising source of polar molecules amenable to deceleration and further cooling.


D1.00091 Long lived dipolar molecules in optical lattices1, STEVEN MOSES, BO YAN, BRIAN NEYENHUIS, JACOB COVEY, AMODSEN CHOTIA, DEBORAH JIN, JUN YE, JILA, NIST, and University of Colorado, Boulder — Ultracold polar molecules in the quantum degenerate regime allow for the realization of quantum systems with long-range, spatially anisotropic interactions. Ultracold fermionic ground-state KRb molecules are created in a three-dimensional optical lattice, where the molecules are shielded from chemically reactive collisions. Lifetimes of around 25 seconds are observed, limited by off-resonant light scattering from the lattice laser. With polar molecules confined in a 3D lattice, we can remove all remaining atoms using resonant light. By reversing the STIRAP process, we recreate Feshbach molecules in a purified 3D lattice, resulting in long lifetimes of up to 20 seconds for Feshbach molecules, limited also by only light scattering. In order to create a colder, denser molecular gas, we have recently implemented a species selective dipole trap that allows us to tune the relative size and position of the K and Rb clouds.

1We acknowledge funding from NIST, NSF, AFOSR-MURI, and the NDSEG Graduate Fellowship.

D1.00092 Cold Rydberg atoms in a CO2 optical dipole trap1, LUIS GONÇALVES, JORGE KONDO, JADER CABRAL, LUIS MARCASSA, University of São Paulo — There has been increasing interest in cold Rydberg atoms over the last several years. The primary reason for this attention is that interactions between Rydberg atoms are strong and lead to many interesting and useful phenomena, which require high atomic density samples. In this work, we have built an experimental setup to investigate cold Rydberg atom collision in a CO2 optical dipole trap. Briefly, we have loaded a Rb standard magneto-optical trap from an atomic vapor provided by a dispenser. Then we turn on 100W CO2 dipole trap and we apply a loading phase, in which the repumper light intensity is reduced and the trapping frequency is detuned to the red. After this phase, the trapping and repumper laser beams are turned off and we wait 100ms for the atoms, that were not trapped, to fall off the dipole trap region due to gravity. Finally, we turn off the dipole trap and excite the Rydberg state using a two photon transition. The Rydberg atoms are detected using pulsed field ionization technique. During the presentation we shall present preliminary results involving collisions between nD states.

1We acknowledge financial support from FAPESP, CNPq, INCT-IQ, AFOSR (FA9550-09-1-0503).

D1.00093 Cold Rydberg atoms in circular states1, DAVID ANDERSON, ANDREW SCHWARZKOPF, GEORG RAITHEL, University of Michigan — Circular-state Rydberg atoms are interesting in that they exhibit a unique combination of extraordinary properties; long lifetimes ($\sim n^5$), large magnetic moments ($l = |n| = n - 1$) and no first order Stark shift. Circular states have found applications in cavity quantum electrodynamics and precision measurements [1,2], among many others. In this work we present the production of circular states in an atom trapping apparatus using an adiabatic state-switching method (the crossed-field method [3]). To date, we have observed lifetimes of adiabatically prepared states of several milliseconds. Their relatively large ionization electric fields have been verified by time-of-flight signatures of ion trajectories. We intend to explore the magnetic trapping of circular state Rydberg atoms, as well as their production and interaction properties in ultra-cold and degenerate samples.


1We would like to acknowledge support from the AFOSR.

D1.00094 Electron temperature dependence on DC applied electric fields in ultracold plasmas1, WEI-TING CHEN, TRUMAN WILSON, JACOB ROBERTS, Colorado State University — One of the features that make ultracold neutral plasmas interesting to study is the ability to create these plasmas at very low initial electron temperatures as compared to other laboratory plasma systems. In this poster, we report on our measurements of initial electron temperatures as a function of applied DC electric field. Our observations indicate that the application of such a field can raise the initial electron temperature, limiting the temperature range over which experiments can be performed unless care is taken to null the DC electric field strength in the region of space where the plasma is created.

1Supported by AFOSR.
D1.00095 Redistribution of atomic population among nearly degenerate Rydberg states through dipole-dipole interactions1, THOMAS J. CARROLL, Ursinus College, DONALD P. FAHEY, MICHAEL W. NOEL, Bryn Mawr College, ALEX MELLUS, JON WARD, Ursinus College — Ultra-cold highly-excited atoms in a magneto-optical trap are strongly coupled by the dipole-dipole interaction. Rubidium atoms that have been excited to the 32d5/2, |m_j| = 1/2 sublevel can exchange energy when an applied static electric field tunes the Stark states into resonance. They do so via the densely packed set of resonant interactions 32d+32d—34p+30g near 0.3 V/cm. Atoms that have exchanged energy and are now in the final p and manifold states can be coupled to a resonance involving 32d5/2, |m_j| = 3/2 and 1/2 states, which redistributes population among the |m_j| sublevels. We present experimental and computational studies that investigate this redistribution.

1This work was supported by the National Science Foundation (grant no. 0655544) and through the Extreme Science and Engineering Discovery Environment (supported by NSF grant no. OCI-1053575).

D1.00096 Vibrational ground state cooling of a neutral atom in a tightly focused optical dipole trap, SYED ALJUNID, GLEB MASLENNIKOV, MARTIN PAESOLD, KADIR DURAK, VICTOR LEONG, CHRISTIAN KURTSIEFER, Centre for Quantum Technologies / Nat. Univ. Singapore — Recent experiments have shown that an efficient interaction between a single trapped atom and light can be established by concentrating light field at the location of the atom by focusing [1-3]. However, to fully exploit the benefits of strong focusing one has to localize the atom at the maximum of the field strength [4]. The position uncertainty due to residual kinetic energy of the atom in the dipole trap (depth ~ 1mK) after molasses cooling is significant (few 100 nm). It limits the interaction between a focused light mode and an atom already for moderate focusing strength [2]. To address this problem we implement a Raman Sideband cooling technique, similar to the one commonly used in ion traps [5], to cool a single 87Rb atom to the ground state of the trap. We have cooled the atom along the transverse trap axis (trap frequency ν_c = 55 kHz), to a mean vibrational state ν_c = 0.55 and investigate the impact on atom-light interfaces.


D1.00097 Occupation numbers of the harmonically trapped few-boson system1, XIANGYU YIN, KEVIN DAILY, DOERTE BLUME, Washington State University — We consider a harmonically trapped dilute N-boson system with pairwise interactions, which are characterized by the two-body s-wave scattering length a_s and the effective range r_e. We construct the one-body density matrix of the weakly-interacting N-boson system and calculate the condensate fraction, defined as the largest occupation number, by employing a perturbative treatment within the framework of second quantization. The condensate fraction for the harmonically trapped N-boson system, calculated within first order perturbation theory, is 1 – (N-1)0.420004a_s^2.

 Corrections of order a_s^3 and a_s^3r_e are also considered. The condensate depletion induced by effective three-body interactions is identified to occur at order a_s^3. Our expression for N = 2 is confirmed by comparing with the expansion of the exact solution [1]. Our results for N = 3 and 4 are compared with high precision ab initio calculations for Bose gases that interact through finite-range two-body model potentials.


D1.00098 Josephson Junctions for a BEC in a Toroidal Trap, CHANGHYUN RYU, ALINA BLINOVA, PAUL BLACKBURN, MALCOLM BOSHIER, Los Alamos National Laboratory — The Josephson Effect is one of the most important consequences of superconductivity and superfluidity. It also plays a crucial role in many technological innovations, including the SQUID. Previous experimental work on creating Josephson Junctions and studying the Josephson Effect with a BEC has mostly relied on somewhat inflexible methods to create the junctions, limiting possible geometries. Here we report our work towards creating arbitrary Josephson Junction arrays based on our “painted potential” method for manipulating BECs. In the previous work, arbitrary potentials for a BEC, including a toroidal trap, were created by using the time averaged optical dipole potential of a 2D scanning laser beam. To implement tunneling junctions, a high resolution long distance objective was installed, allowing painting of arbitrary potentials with a resolution of 1.5 micron.

This configuration can be used to sense rotation and create a Schrödinger cat state of different flow states. Towards this goal, we painted two symmetric Josephson Junctions for a BEC in a toroidal trap and studied Josephson effects in this setup. In this poster we will report progress on this experiment.

D1.00099 Preparation of a mixture of ultracold Cs-133 and Li-6 atoms for the study of inter-species collisions, SIH-JUANG TUNG, COLIN PARKER, JACOB JOHANSEN, CHENG CHIN, The University of Chicago — We report experimental progress toward a Bose-Fermi mixture of Cs-133 (Boson) and Li-6 (Fermion) atoms. Based on a dual-species magneto-optical trap, we trap 10^8 Cs atoms and 10^9 Li atoms at temperatures of ~30 μK and ~300 μK, respectively. Further optical cooling, including optical molasses and degenerate Raman sideband cooling, have also been implemented to cool Cs atoms down to a temperature of 2 μK. The cooling allows us to load 2*10^7 Cs atoms into a crossed dipole trap. We plan to load Li atoms into a second dipole trap, which spatially separates Li atoms from Cs atoms. After evaporative cooling Li atoms down to a temperature of few μK in the second dipole trap, we will merge the two samples to study collisional properties between the two species. The collisional properties will provide essential knowledge for us to work towards achieving a degenerate quantum gas of cesium and lithium mixture. Furthermore, the result will give important information to identify Li-Cs molecular states below the continuum, from which a scalable quantum information processing can be implemented.

D1.00100 Experiments with Non-Equilibrium Co- and Counter-circulating Vortices, MICHAEL RAY, EMINE ALTINTAS, THOMAS LANGIN, DAVID HALL, Amherst College — We present an experimental study of real-time dynamics of small clusters of vortices in a trapped Bose-Einstein condensate. These dynamics have been typically understood in terms of vortex-vortex interactions and interactions between each vortex and the condensate background. We demonstrate that thermal atoms can also play an important role, and a rotating thermal cloud can be used in conjunction with established techniques to create and manipulate vortex clusters. The effect of co- and counter-rotating a thermal cloud is to move the vortices in towards or away from the center of the condensate, respectively. With this technique different configurations of vortices in the cluster can be readily achieved.
**D1.00101 Spinor dynamics in a $^{23}$Na Bose-Einstein condensate**, HYEWON PECHKIS, JONATHAN WRUBEL, JOII, NIST and Univ. of Maryland, PAUL GRIFFIN, Univ. of Strathclyde, RYAN BARNETT, EITE TIESINGA, PAUL LETT, JOII, NIST and Univ. of Maryland — Spinor Bose-Einstein condensates (BECs) are characterized by an additional internal degree of freedom, which results in a vector order parameter. In particular, this system may be used to produce an internal state matter-wave amplifier, as well as spin-squeezed states. In order to pursue these goals it is critical to have an accurate measurement of the spin-dependent interaction energy $c_2$, which is proportional to the difference in scattering lengths $a_{F=2}$ and $a_{F=0}$. The spin-dependent interaction energy determines the ground-state structure as well as the dynamical properties of spinor condensates. A recent result used Feshbach resonance measurements in a BEC to create realistic atomic potentials for sodium and yielded a value which is approximately a factor of two larger than the only measurement in a sodium spinor condensate. Here we discuss the difficulties associated with measuring $c_2$ in sodium, as well as a revised measurement from spinor dynamics. In addition we will discuss our experiments on microwave-dressed spinor states, seeded, and unseeded matter-wave amplification.

**D1.00102 Atom Interferometric Holography and Arbitrary Pattern Nanolithography Using Bose-Einstein Condensates**, SELIM SHAHRARI, MAY KIM, JONATHAN TROSSMAN, JOHN KETTERTSON, MOHAMMED FOUDA, REN-PENG FANG, Northwestern University — We describe a technique where atomic interferometry along with light-shift induced, two dimensional phase imprinting with optical pulses are used to produce three dimensional holographic patterns of atoms, using a Bose-Einstein Condensate as a source. We also show how a variation of this technique can be used to realize arbitrary pattern nanolithography with a feature size as small as 2 nm. We have used the Gross-Pitaevskii equations to model the evolution of the condensate order parameter through free space as well as during interaction with the optical fields, using typical values of scattering lengths, in the absence of Feshbach resonances. In our scheme, the condensate is first split into two components in different hyperfine states, using a Raman pulse. Detuned optical pulses are then used to imprint desired phase profiles on one or both parts of the split components. For proper choice of pulses and phase patterns, the atoms form a three-dimensional hologram or a two-dimensional pattern, upon recombination of the two parts using additional Raman pulses. These techniques could be used for nanolithography by transferring the pattern to coinage metals, or to produce various topological patterns of condensates for fundamental studies.

**D1.00103 Quantum degenerate Fermi and Bose gases of dysprosium**, NATHANIEL BURDICK, MINGWU LU, BENJAMIN LEV, Stanford University — Advances in the quantum manipulation of ultracold atomic gases are opening a new frontier in the quest to better understand strongly correlated matter. By exploiting the long-range and anisotropic character of the dipole-dipole interaction, we hope to create novel forms of quantum mesophases, states of quantum soft matter intermediate between canonical states of order and disorder. Our group has recently created quantum degenerate gases of both bosonic and fermionic isotopes of dysprosium, the most magnetic atom. With this most dipolar degenerate Fermi gas yet created, we intend to investigate quantum liquid crystals, mesophases thought to exist in, e.g., high Tc cuprate superconductors.

We acknowledge support from AFOSR, NSF, and ARO/MURI.

**D1.00104 Universal Thermodynamics and Dimensional Crossover of a Strongly Interacting Fermi Gas**, ARIEL SOMMER, MARK KU, LAWRENCE CHEUK, WASEEM BAKR, TARIK YEFSAH, MARTIN ZWIERLEIN, Department of Physics, MIT-Harvard Center for Ultracold Atoms, and Research Laboratory of Electronics, MIT, Cambridge, Massachusetts 02139, USA — We have measured with high precision the universal thermodynamics of a unitary Fermi gas of $^6$Li atoms using a novel method that requires no fit or external thermometer. This has allowed us to observe the first direct thermodynamic signature of the superfluid transition, revealed in the compressibility, the chemical potential, the entropy, and the heat capacity. Our technique can be used to realize arbitrary pattern nanolithography with a feature size as small as 2 nm, similar to the Gross-Pitaevskii equations to model the evolution of the condensate order parameter through free space as well as during interaction with the optical fields, using typical values of scattering lengths, in the absence of Feshbach resonances. In a separate experiment, we follow the evolution of fermionic pairing from three dimensions to two dimensions. Using a 1D optical lattice, we confine $^6$Li atoms into stacks of two-dimensional pancakes. The reduced dimensionality leads to a 2-body bound state even on the BCS side of a Feshbach resonance. We have measured the binding energy of such pairs across the dimensional crossover using RF spectroscopy. Surprisingly, the binding energy closely follows the theoretical prediction for two particles in vacuum.

This work was supported by the NSF, AFOSR-MURI, ARO-MURI, ONR, DARPA YFA, a grant from the Army Research Office with funding from the DARPA OLE program, the David and Lucile Packard Foundation and the Alfred P. Sloan Foundation.

**D1.00105 Inter-band dynamics in a tunable hexagonal lattice**, PATRICK WINDPASSINGER, MALTE WEINBERG, JULIETTE SIMONET, JULIAN STRUCK, CHRISTOPH OECSCHLAGER, DIRK LÜEHMANN, KLAUS SENGSTOCK, Institute of Laser Physics, Universitäet Hamburg — Hexagonal lattices have recently attracted a lot of attention in the condensed matter community and beyond. Upon other intriguing features, their unique band structure exhibits Dirac cones at the corners of the Brillouin zone of the two lowest energy bands. Here, we report on the experimental observation of momentum-resolved inter-band dynamics of ultracold bosons between the two lowest Bloch bands (s- and p-band) of a hexagonal optical lattice with tunable band structure. Due to the spin-dependency of the lattice potential [1,2], a rotation of the magnetic quantization axis and the choice of the atomic spin state allow for an in-situ manipulation of the lattice structure from hexagonal to triangular geometry. It is thus possible to modify the band structure and open a gap at the Dirac cones. The loading of atoms into the excited band is achieved by a microwave transition between different spin states which in certain cases is only allowed as a result of interaction effects. We observe the time-dependent population of quasi momenta, revealing a striking influence of the existence of Dirac cones on the dynamics of atoms in the first two energy bands.

1. P. Soltan-Panahi et al., Nature Physics 7, 43 (2011)

**D1.00106 Probing many-body physics with an optical lattice clock**, MICHAEL BISHOF, MICHAEL J. MARTIN, MATTHEW D. SWALLOWS, CRAIG BENKO, JAVIER VON STECHER, JILA, NIST, and University of Colorado at Boulder, ALEXEY V. GORSKHOV, Institute for Quantum Information, California Institute of Technology, ANA MARIA REY, JUN YE, JILA, NIST, and University of Colorado at Boulder — Advances in ultra-stable lasers now permit sub-Hz resolution of optical atomic transitions. At this level, interactions can dominate dynamics of the interrogated atoms, even for ultracold spin-polarized fermions. Density dependent frequency shifts of the $^{133}$Cs $^{1s_0} F=2 \rightarrow ^{1s_2} F=3$ clock transition were first observed in $^{133}$Sr [1]. Originally, this effect was attributed to s-wave interactions enabled by inhomogeneous excitations [2,3]. More recently, evidence for p-wave interactions was reported in $^{171}$Yb [4]. Understanding interactions in thses systems is necessary to improve clock accuracy and stability. Moreover, such an understanding will enable optical lattice clock systems to serve as quantum simulators for open, driven, strongly-interacting quantum systems at the mesoscopic scale. We present a comprehensive evaluation and understanding of the interactions present in a $^{133}$Sr optical lattice clock system under various conditions using a mean-field theory. The regime in which only a genuine many-body treatment can properly describe our system is within immediate experimental reach.

2. A. M. Rey et al., PRL 103, 260402 (2009).
D1.00107 Dynamics of interacting fermions in optical lattices, JASPER SIMON KRAUSER, JANNE HEINZE, NICK FLÄSCHNER, SØREN GÖTZE, CHRISTOPH BECKER, KLAUS SENGSTOCK, Institute of Laser Physics, University of Hamburg, BFM TEAM — Quantum gases in optical lattices offer a wide range of applications for quantum simulation due to fully tunable lattice and atomic interaction parameters. In particular fermions are of high interest due to their resemblance with conventional solid state systems. In this poster, we present results on ultracold fermionic quantum gases of $^{41}$K in optical lattices. We investigate the excitation spectrum with full momentum resolution and resolve an interaction-induced shift of the band structure. The excited particle-hole pairs show confinement-induced higher orbital dynamics in good agreement with a single particle model. To tune the interaction between the fermions, we explore Feshbach resonances in different binary mixtures. We study stable or unstable mixtures and observe a variety of resonances in good agreement with calculations. Our results open new perspectives to study dynamical properties of interacting Fermi spin-mixtures in lattice systems.

D1.00108 ABSTRACT WITHDRAWN –

D1.00109 Superfluidity of Bosons in Optical lattices with Spin-Orbit coupling, QINQIN LU, Louisiana State University — Recent experimental and theoretical work has explored artificial spin-orbit coupling induced among two species of boson. Here we examine superfluidity of a cold gas of bosons with spin-orbit coupling in a periodic optical lattice, in the presence of additional short-range interactions. We compute the density distribution after free expansion from the lattice as a probe of superfluidity, and phase transitions, of the trapped gas.

1This work was supported by the Louisiana Board of Regents

D1.00110 Probing the 1D-3D Crossover of a Spin-Imbalanced Fermi Gas, MELISSA REVELLE, BEN A. OLSEN, YEAN-AN LIAO, RANDALL G. HULET, Department of Physics and Astronomy and Rice Quantum Institute, Rice University, Houston, TX 77005 — We have previously mapped the phase diagram of a 1D spin-imbalanced Fermi gas by confining the atoms in an array of tubes using a 2D optical lattice. Within each tube we observed separation of the atoms into a partially polarized superfluid core and fully paired or fully polarized wings (depending on the spin polarization). In 3D, the phase separation is inverted, such that the cloud center is fully paired. We investigate the transition from a 1D to 3D gas by smoothly varying the lattice depth which changes the tunneling between the tubes. This allows us to study how the spin density changes as a function of inter-tube coupling. By varying the lattice depth quickly, we can measure the spin transport properties in a strongly interacting system. Progress will be reported.

3Supported by DARPA, NSF, and ONR.


D1.00111 The realization of a tunable optical kagome lattice using ultracold atoms, JENNIE GUZMAN, CLAIRE K. THOMAS, PAVAN HOSUR, THOMAS BARTER, GYU-BOONG JO, ASHVIN VISHWANATH, DAN M. STAMPER-KURN, University of California Berkeley — We report the realization of a two-dimensional kagome lattice for ultracold $^{87}$Rb atoms by overlaying two commensurate triangular optical lattices generated by light at the wavelengths of 532 and 1064 nm. Stabilizing and tuning the relative position of the two triangular lattices, different lattice geometries including a kagome, a one-dimensional stripe, and a decorated triangular lattice are explored. We characterize these geometries using Kapitza-Dirac diffraction and by analyzing the Bloch-state composition of a superfluid released suddenly from the lattice. The tunable optical superlattice implemented in this work offers a new way to investigate a possible superfluid (SF) to Mott insulator (MI) phase transition by tuning the lattice geometries with different number of nearest neighbors. In this poster, we report the experimental progress on the geometry-induced SF-MI phase transition between triangular and kagome lattice geometries.

D1.00112 Li-7 Machine for Quantum Magnetism Experiments, JESSE AMATO-GRILL, IVANA DIMITROVA, NIKLAS JEPSEN, MICHAEL MESSER, MIT, GRACIANA PUENTES, ICFO, DAVID WELD, UC Santa Barbara, DAVID PRITCHARD, WOLFGANG KETTERLE, MIT, CENTER FOR ULTRACOLD ATOMS COLLABORATION — A new Li-7 Bose-Einstein condensate experiment (currently under construction) will realize and probe novel magnetic phases of matter. Because of the small mass of the Li atom and tight lattice spacing, we expect to achieve a 100-fold increase in tunneling rate between lattice sites over comparable Rb-87 optical lattice emulator experiments. These improvements will allow us to access new regimes in quantum magnetic phase transitions and spin dynamics.

D1.00113 Progress toward the installation of a two-dimensional accordion lattice for ultra-cold atoms, JOHN HUCKANS, Bloomsburg University of Pennsylvania, IAN SPIELMAN, NIST Gaithersburg — One of the benefits of using ultra-cold atoms in optical lattices to perform traditional condensed matter style experiments is the opportunity to continuously change the lattice periodicity by as much as one order of magnitude in each dimension. We have constructed a wide-range two-dimensional accordion optical lattice by steering four paraxial laser beams onto an atom cloud using a single large annular lens. The device has been aligned and bench tested without atoms. It is now being installed in an apparatus for producing $^{87}$Rb Bose-Einstein condensates and artificial magnetic fields. We present preliminary data on the performance of the device with atoms.

1Bloomsburg University Research and Disciplinary Grant.


D1.00114 The impact of spatial correlation on the tunneling dynamics of few-boson mixtures in a combined triple well and harmonic trap, LUSHUIJAI CAO, IOANNIS BROUZOS, BUDHADITYA CHATTERJEE, PETER SCHMELCHER, Zentrum für Optische Quantentechnologien, Universität Hamburg, Germany — We investigate the tunneling properties of a two-species few-boson mixture in a one-dimensional triple well and harmonic trap. The mixture is prepared in an initial state with a strong spatial correlation for one species and a complete localization for the other species. We observe a correlation-induced tunneling process in the weak interspecies interaction regime. The onset of the interspecies interaction disturbs the spatial correlation of one species and induces tunneling among the correlated wells. The corresponding tunneling properties can be controlled by the spatial correlations with an underlying mechanism which is inherently different from the well known resonant tunneling process. We also observe the correlated tunneling of both species in the intermediate interspecies interaction regime and the tunneling via higher band states for strong interactions.

1L.C. and P.S. gratefully acknowledge financial support by the Deutsche Forschungsgemeinschaft (DFG), and B.C. thanks support from the Landesexzellenzinitiative Hamburg, financed by Science and Research Foundation Hamburg and Joachim Herz Stiftung.
D1.00115 Nonequilibrium Dynamics of Interacting Two Particle in Driven Cold Atomic System, WONHO JHE, YONGHEE KIM, SOYOUNG SHIN, Department of Physics and Astronomy, Seoul National University, MARK DYKMAN, Department of Physics and Astronomy, Michigan State University — We investigate the nonequilibrium fluctuational dynamics in the dynamic bistable state which is based on the parametrically modulated cold atomic system. In the absence of interaction between atoms, each atom consider as a single nonlinear oscillator and its dynamics is described by the activation energy and most probable escape path. But if the interaction exit, system exhibit complicate cooperative dynamics which is hard to deal with. We simulate the interacting two particle system for the model system of the interacting many atom system. In our work, the interaction has the form $f_{ij} = -f_{0i} f_{j0} [z_i - z_j]$ which describe the effective attractive interaction called "shadow force" in magneto-optical trap. The simulation results show clear evidence that two particle correlation grows as the interaction strength increases below the certain value. This is closely related to the spontaneous symmetry breaking transition in the parametrically modulated cold atomic system.

D1.00116 Fractional Quantum Hall Effect of lossy Rydberg Dark-State Polaritons, FABIAN GRUSDT, MICHAEL FLEISCHHAUER, MICHAEL HÖNING, Department of Physics and Research Center OPTIMAS, TU Kaiserslautern, Germany, JOHANNES OTTERT-BACH, Harvard Quantum Optics Center, Harvard University, Cambridge, Massachusetts, USA — Dark-state-polaritons (DSP) are bosonic quasiparticles arising in the interaction of light with 3-level atoms under conditions of electromagnetically induced transparency (EIT). When exposed to a strong artificial magnetic field, they can enter the lowest Landau level regime. With additional long range interactions, as realized e.g. when the 3-level atom contains a Rydberg-exited state, DSPs are natural candidates for a realization of the bosonic fractional quantum Hall effect. Besides their high controllability, they offer the possibility to examine open quantum Hall systems. We show how highly-correlated quantum Hall states of DSPs can be prepared, making use of nonlinear polarization losses. The possibility of realizing these states as stationary states of open systems is investigated. We propose a realistic quantum-optical setup, and show that different fractional quantum Hall states can be prepared, manipulated and observed. Numerical and analytical results for the excitation gaps of the $\nu = 1/2p$ Laughlin states are presented.

D1.00117 Detecting FFLO Pairs in a 1D Spin-Polarized Fermi Gas by Time-of-Flight Expansion, DAVID W. TAM, MELISSA REVELLE, BEN A. OSLEN, RANDALL G. HULET, Department of Physics and Astronomy, Rice University, Houston, TX 77005 — We previously reported the experimental phase diagram of a 1D spin-imbalanced Fermi gas consisting of ultracold $^6$Li atoms prepared in two unequally-populated hyperfine sublevels. This system exhibits three phases: a uniformly paired phase, a fully-polarized phase consisting of only spin-up atoms, and a partially-polarized phase that is predicted to be the elusive FFLO fluid. The FFLO state accommodates the mismatched Fermi surfaces by forming atom pairs with nonzero center-of-mass momentum, which we aim to directly characterize via time-of-flight expansion imaging. We confine the atoms in an array of 1D tubes formed from a 2D optical lattice. A blue-detuned anti-trapping laser beam will be applied to exactly cancel the axial harmonic confinement, allowing the atoms to freely expand in 1D. We will report the progress of our experiment.

D1.00118 Quantum Calculations of Ultracold Molecule Formation by Nanosecond-Timescale Frequency-Chirped Pulses, J. L. CARINI, C. E. ROGERS III, P. L. GOULD, Department of Physics, University of Connecticut, Storrs, CT 06269, USA, J. A. PECCHISI, Naval Research Laboratory, 4555 Overlook Avenue S.W., Washington, DC 20375, USA, S. KALLUSH, Department of Physics and Optical Engineering, ORT Braude, P.O. Box 78, Karmiel, Israel, R. KOSLOFF, Department of Physical Chemistry and the Fritz Haber Research Center for Molecular Dynamics, The Hebrew University, 91904, Jerusalem, Israel — We report on the results of quantum calculations of $^8$Rb$_2$ formation from ultracold atoms by pulses of frequency-chirped light on the nanosecond timescale. This time-dependent photoassociation is modeled by following the dynamics of the collisional wave functions on both ground-state and excited-state potentials in the presence of the chirped light. Because of the relatively long time scales involved, spontaneous emission from the excited state must be accounted for. Results of the calculations are compared to recent measurements made with 40 ns FHWM Gaussian pulses and chirps that sweep 1 GHz in 100 ns. Dependencies on pulse intensity and chirp direction will be presented. This work is supported by DOE.

D1.00119 Towards Photoassociation and Ultracold Collisions in Cs/K trap, MARIN PICHLER, JOEL BERGER, DAVID HALL, Department of Physics and Astronomy, Goucher College, Baltimore, MD — We present our setup and recent results in simultaneous trapping of potassium and cesium atoms in a mixed MOT. Our setup is based on diode lasers and a tapered amplifier for producing all trapping and repumping beam frequencies. The beam geometry allows for optimal overlap of two ultracold atom clouds, necessary for studying ultracold collisions and photoassociation. Fluorescence and trap-loss detection is used for both studies. We outline mechanism for creating and detecting deeply bound $X^1\Sigma^+$ ground state KCs molecules, and discuss particular characteristic of ultracold KCs.

D1.00120 Cold and ultracold H$_2$-H$_2$ collisions on high accuracy ab initio potentials, N. BALAKRISHNAN, S. FONSECA DOS SANTOS, Department of Chemistry, University of Nevada Las Vegas, NV 89154, R. C. FORREY, Penn State University, Berks Campus, Reading, PA 19610, P. C. STANCIL, University of Georgia, Athens, GA 30602, P. JANKOWSKI, Department of quantum chemistry, Institute of Chemistry, Nicolaus Copernicus University, PL-87-100 Torun, Poland, K. SZALEWICZ, Department of Physics and Astronomy, University of Delaware, Newark, Delaware 19716 — We report quantum calculations of rovibrational transitions in H$_2$ + H$_2$ collisions on different ab initio potential surfaces (PESs). The PESs employed include the six-dimensional interaction potential of Hinde [1] and a hybrid potential constructed from the Hinde potential and the high accuracy 4-dimensional PES of Patkowski et al. [2]. Results show that vibrational relaxation cross sections are sensitive to details of the potentials at low energies but the sensitivity is significantly suppressed for quasiresonant transitions that involve small energy gaps and that conserve the total rotational angular momentum of the colliding molecules. Additionally, we present results for $H_2^+(v = 2) + H_2^+(v = 0)$ collisions and explore competition between vibration-vibration (VV) transfer leading to $H_2^+(v = 1) + H_2^+(v = 0)$ products and vibration-translation (VT) transfer yielding $H_2^+(v = 1) + H_2^+(v = 0)$ products. Results show that the VV process dominates over the VT process, in agreement with available experimental data. [1] Robert J. Hinde, J. Chem. Phys. 128, 154308 (2008). [2] K. Patkowski, W. Cencek, P. Jankowski, K. Szalewicz, J. B. Mehli, G. Garberoglio, and A. H. Harvey, J. Chem. Phys. 129, 094304 (2008).

D1.00121 Analytic coupled channel calculation of ultracold three-body collision rates, EDMUND MEYER, B. D. ESRY, Department of Physics, Kansas State University — We analyze three-body recombination for positive two-body $s$-wave scattering lengths. Using the adiabatic hyperspherical representation as a starting point, we introduce coupling between the three-body continuum and the weakly bound diatom plus atom channel in the vicinity of $R \sim a$—the location where rigorous calculations have shown the coupling to peak [1]. In order to model loss to deep bound diatom channels, we introduce a complex short-range $K$-matrix. Analytic expressions for the loss rates are derived and we recover the behavior found previously [2], including the overall $s^4$ scaling for identical bosons as well as the log-periodic modulation due to Efimov physics. Our formulation permits straightforward extensions to other symmetries and higher energies.


1 Supported by the National Science Foundation.
D1.00122 Theoretical and Experimental evidence for the observation of trilobite states in Cs. JONATHAN TALLANT, DONALD BOOTH, JAMES SHAFFER, University of Oklahoma, SETH RITTMENHOUSE, HOSEIN SADEGHPOUR, ITAMP, Harvard-Smithsonian Center for Astrophysics — A novel binding mechanism arises from the attractive, low-energy scattering of a Rydberg electron from a neighboring ground state atom. The states formed by this binding mechanism are referred to as trilobite or trilobite-like states. A primary difference between the trilobite and trilobite-like states is the angular momentum of the Rydberg atom, which is dominated by an s-wave Rydberg orbit. The larger angular momentum of trilobite states can change the properties of the molecules that form. For example, large l trilobite molecules are predicted to have giant, body-fixed permanent dipole moments (\sim 1KD). Trilobite-like states were observed in 2009 in Rb [1]. We present experimental evidence for trilobite molecules formed as a result of state mixing between the nS and (n-4) \geq F states in Cs, due to the small non-integer quantum defects in the Cs s state, and compare the observation with theoretical results.


D1.00123 Universal relations in ultracold three-body observables associated with Efimov physics[1]. JOSE P. D’INCAO, JIA WANG, YIJUN WANG, CHRIS H. GREENE, Department of Physics and JILA, University of Colorado at Boulder — We explore universal aspects in homonuclear and heteronuclear three-body systems displaying the Efimov effect using the adiabatic hyperspherical representation. The existence of repulsive barrier in the three-body adiabatic potentials prevent atoms to approach small distances and, consequently, to access the region where the details of the interactions are important. As a result many of the properties of the system becomes universal. Here, we study the universal relation between the position of Efimov resonances for positive and negative scattering lengths with the goal of understanding current discrepancies between theory and experiment.

[1]Supported by National Science Foundation and AFOSR-MURI

D1.00124 Ultracold collisions properties of two dipoles in a Fermi sea[1], W. BLAKE LAING[2], CHRIS WALSH, HONG Y. LING, Rowan University — We investigate the low-energy scattering properties of two bosonic dipoles in the presence of a Fermi sea. The interaction between each dipole and the Fermi sea gives rise to an induced potential between the dipoles which is oscillatory, isotropic, and (approximately) bounded by 1/r^3. We numerically investigate the momentum dependence of the low-energy s-wave phase shift. The presence of the Fermi sea adds a potential experimental control in few-body phenomena.

[1] This material is based upon work supported by the U.S. Army Research Office
[2]WBL thanks Yujun Wang, Brett Esry, and Michael Morrison for helpful discussions

D1.00125 Atom trapping laboratory for upper level undergraduate students[1], C. MOK, S. WINTER, H. BEICA, B. BARRETT, R. BERTHIAUME, A. VOROZCOVS, F. YACHOUA, N. AFKHAMI-JEDDI, R. MARANTS, M. AGGARWAL, A. KUMARAKRISHNAN, Department of Physics and Astronomy, York University — We present an overview of experiments covered in two semester-length laboratory courses dedicated to laser spectroscopy and atom trapping. These courses constitute a powerful approach for teaching experimental physics in a manner that is both contemporary and capable of providing the background and skills relevant to a variety of research laboratories. The courses are designed to be accessible for all undergraduate streams in physics and applied physics as well as incoming graduate students. In the introductory course, students carry out experiments in several laboratories and laser physics. In a follow up course, students trap atoms in a magneto-optical trap and carry out preliminary investigations of the properties of laser cooled atoms based on the expertise acquired in the first course. We discuss details of experiments, impact, possible course formats, budgetary requirements, and challenges related to long-term maintenance. The experiments described here have operated reliably for over five years.

[1]Work supported by Optech Inc. and York University

D1.00126 Polarization Effects in STIRAP Between Triplet He States[1], YUAN SUN, PETR M. ANISIMOVA, HAROLD METCALF, Stony Brook University, Stony Brook NY 11794-3800 — We studied the effect of laser polarization on the excitation of helium atoms from the metastable 2^3S state to Rydberg nS states via the intermediate 3^3P states. For STIRAP, an infrared laser connects the 3^3P_{2,1,0} and nS levels, and then 389 nm UV light drives the 2^3S_1 to 3^3P_{2,1,0} transition. The light polarizations determine the nature of the couplings between the different Zeeman sublevels, and interference may arise in those different excitation paths. Rydberg atoms are suitable for this experiment because of their relatively long life times so the nS populations are readily measured. The correspondence between polarizations and nS level populations have been studied both theoretically and experimentally, and the interference patterns are revealed.

[1]Supported by ONR.

D1.00127 Saturated absorption spectroscopy of Ho atoms for laser cooling experiments[1], J. MIAO, J. HOSTETTER, M. SAFFMAN, University of Wisconsin — We present spectroscopy measurements of the 410.5 nm cooling transition in Ho using a source based on a frequency doubled diode laser. The laser is locked to the Ho F = 11 – F' = 12 transition between resolved hyperfine states using saturated absorption spectroscopy in a hollow cathode cell. Progress towards using the 410.5 nm source for laser cooling and trapping of Ho atoms generated in an effusion cell will be presented.

[1]This work was supported by NSF.

D1.00128 Experimental apparatus for ultracold Rb-K mixture. JONGCHUL MUN, SUNG JONG PARK, JIHO NOH, CHANG YONG PARK, WON-KYU LEE, DAI-HYUK YU, KRIS — We describe our experimental apparatus for producing ultracold 87Rb and 40K mixture. Double MOT(Magneto-Optical trap) system consisting of 2-dimensional MOT, and 3-dimensional MOT is employed in our system. The 2-dimensional MOT produces an intense cold atomic beam utilizing a two-color pushing laser beam that could adjust the mean velocity of the atomic beam. The Rb atoms from 2D MOT are collected in the 3D MOT for production of BEC(Bose-Einstein Condensate). After MOT compression and polarization gradient cooling, atoms are captured in the QUIC(Quadrupole Ioffe Configuration) magnetic trap for the rf induced evaporative cooling. Our system produces pure condensates with the atoms number of 10^5 range.
D1.00129 Toward Laser Cooling without Spontaneous Emission¹, CHRISTOPHER CORDER, BRIAN ARNOLD, HAROLD METCALF. Stony Brook University, Stony Brook, NY 11794-3800 — The bichromatic force (BF) can be used for laser cooling in the absence of closed cycling transitions because it can cool without spontaneous emission (SE)⁴. Previous BF experiments have used transitions with long characteristic cooling times τc = Δp/|F| ∼ π/4ωc, thereby allowing many SE events. We are building an experiment using the 2³S₁ → 3¹P₂ transition at λ = 389 nm in He because its large recoil frequency ωc = 2π × 330 kHz makes τc comparable to the 3¹P₂ lifetime ~100 ns so that there would be minimal SE events during τc. We will describe our experiment as well as studies of the density matrix solutions for the force integrated over short interaction times accounting for atomic velocity changes. These solutions are used for Monte Carlo simulations of experimental conditions incorporating He beam trajectories and velocity distributions.

¹Supported by ONR and NJSGC

D1.00130 Spin Exchange Cooling in an Ultracold ⁸⁵/⁸⁷Rb Mixture¹, REBEKAH FERRIER, MATHEW HAMILTON, JACOB ROBERTS, Colorado State University — Through the combination of the application of a magnetic field and using optical pumping for spin polarization, it is possible to use spin-exchange collisions to cool a mixture of ultracold ⁸⁵Rb and ⁸⁷Rb atoms trapped in an optical trap. This cooling can be accomplished without requiring the intrinsic loss of atoms from the gas. The use of two isotopes is also advantageous in mitigating reabsorption of the optical pumping light in the gas, a significant limitation in non-evaporative cooling. We report on our most recent implementation of this cooling technique and discuss the cooling performance with improved initial atom density, optical trap confinement, microwave coupling for optical pumping, and optical pumping scheme.

¹Supported by AFOSR

D1.00131 Magic wavelengths and other properties of Li for optical cooling and trapping¹. MARIANNA SAFRONOVA, University of Delaware, ULYANA SAFRONOVA, University of Nevada, Reno, CHARLES W. CLARK, JQI, NIST and the University of Maryland — Using first-principles calculations, we identify magic wavelengths λ for the 2s − 2p½, 2s − 2p½, 2s − 3p½, and 2s − 2p½ transitions in Li. The ns and np atomic levels have the same ac Stark shifts at the corresponding magic wavelength, which facilitates state-insensitive optical cooling and trapping. Possible differences between the positions of magic wavelengths in ⁶Li and ⁷Li are investigated. Our approach uses high-precision, relativistic all-order method in which all single, double, and partial triple excitations of the Dirac-Fock wave functions are included to all orders of perturbation theory. Recommended values are provided for a large number of Li electric-dipole matrix elements. Trends of dynamic polarizabilities of the ground and 2p½, 3s, and 3p½ states are investigated. Uncertainties of all recommended values are estimated. Implications of our results for optical cooling and trapping of Li are discussed.

¹This research was performed under the sponsorship of the US Department of Commerce, National Institute of Standards and Technology.

D1.00132 Simulations of streamers in N₂:O₂ and N₂:CO₂ mixtures using highly accurate transport data. SASA DUJKO, Institute of Physics, University of Belgrade, PO Box 68, Zemun 11080, Belgrade, Serbia, GIDEON WORMEESTER, Centrum Wiskunde & Informatica (CWI), P.O.Box 94079, 1090 GB Amsterdam, The Netherlands, RON WHITE, ARC Centre for Antimatter-Matter Studies, School of Engineering and Physical Sciences, James Cook University, Townsville 4810, Australia, ZORAN PETROVIC, Institute of Physics, University of Belgrade, PO Box 68, Zemun 11080, Belgrade, Serbia, UTE EBERT, Centrum Wiskunde & Informatica (CWI), P.O.Box 94079, 1090 GB Amsterdam, The Netherlands — Streamers are growing filaments of weakly-ionized non-stationary plasma produced by an ionization front that moves through non-ionized matter. They can emerge in a wide variety of gases and pressures. Previous experiments and numerical simulations have shown that streamer properties such as velocity and diameter are remarkably insensitive to changes in gas composition. In our numerical simulations, we use a fluid model to compute the densities of charged particles, obeying drift-diffusion-reaction equations. Previously, we have used a constant, empirical value for the diffusion and mobility coefficients in these simulations. We will describe our experiment as well as studies of the density matrix solutions for the force integrated over short interaction times accounting for atomic velocity changes. These solutions are used for Monte Carlo simulations of experimental conditions incorporating He beam trajectories and velocity distributions.

D1.00133 FUNDAMENTAL SYMMETRIES AND PRECISION MEASUREMENTS I

D1.00134 Precise determination of atomic g-factor ratios from a dual isotope magneto-optical trap¹. I. CHAN, B. BARRETT, A. CAREW, C. MOK, A. KUMARAKRISHNAN, Department of Physics and Astronomy, York University — We demonstrate a technique, for carrying out precise measurements of atomic g-factor ratios, which relies on measurements of Larmor oscillations from coherences between magnetic sublevels in the ground states of ⁸⁵Rb and ⁸⁷Rb atoms confined in a dual isotope magneto-optical trap. We show that a measurement of gP(⁸⁷)/gP(⁸⁵) with a resolution of 0.69 parts per 10⁶ is possible by recording the ratio of Larmor frequencies in the presence of a constant magnetic field. This represents the most precise single measurement of gP(⁸⁷)/gP(⁸⁵) without correcting for systematic effects (I. Chan et al., Phys. Rev. A 84, 032509 (2011)).

¹Work supported by CFI, OIT, NSERC, OCE, and York University

D1.00135 A Search for Nonstandard Neutron Spin Interactions using Dual Species Xenon Nuclear Magnetic Resonance , MICHAEL BULATOWICZ, MICHAEL LARSEN, JAMES MIRIJANIAN, Northrop Grumman - Navigation Systems Division, CHANGBO FU, HAIYANG YAN, ERICK SMITH, MIKE SNOW, Indiana University, THAD WALKER, University of Wisconsin — NMR measurements using polarized noble gases can constrain possible exotic spin-dependent interactions involving nucleons. A differential measurement insensitive to magnetic field fluctuations can be performed using a mixture of two polarized species with different ratios of nucleon spin to magnetic moment. We used the NMR cell test station at Northrop Grumman Corporation (NGC) (developed to evaluate dual species xenon vapor cells for the Nuclear Magnetic Resonance Gyroscope) to search for NMR frequency shifts of xenon-129 and xenon-131 when a non-magnetic zirconia rod is modulated near the NMR cell. We simultaneously excited both Xe isotopes and detected free-induction-decay transients. In combination with theoretical calculations of the neutron spin contribution to the nuclear angular momentum, the measurements put a new upper bound on possible monopole-dipole interactions of the neutron for ranges around 1mm. This work is supported by the NGR Internal Research and Development (IRAD) funding, the Department of Energy, and the NSF.
D1.00136 Precise measurement of the scalar polarizability of $^{115}\text{In}$ in an indium atomic beam

ANDERS SCHNEIDER, GAMBHIR RANJIT, NATHAN SCHINE, P.K. MAJUMDER, Williams College, Dept. of Physics — In recent years, we have pursued a series of precise atomic structure measurements in Group III elements thallium and indium in order to test recent ab initio theory calculations in these three-valance-electron systems. We are currently completing a precision measurement of the indium scalar polarizability within the 410 nm 5P$_{1/2} \rightarrow 6S_{1/2}$ transition using a GaN semiconductor laser interacting transversely with a collimated indium atomic beam in the presence of precisely calibrated high voltage electric field. We use 100 MHz laser frequency modulation and RF lock-in detection to obtain a high-resolution absorption signal despite indium beam optical depths of $< 10^{-3}$. An in-vacuum chopper wheel modulates the atomic beam and provides further noise and background reduction. Our current level of precision produces 1% statistical measurement of the Stark Shift in less than one hour of data collection. Our preliminary results for the scalar polarizability within this transition agree with a previous result and we expect an eventual tenfold improvement in accuracy, providing a challenge to ongoing atomic theory calculations. Current results will be presented.


D1.00137 Current Work to Improve Precision in Measurements of Helium Fine Structure

NIMA HASSAN REZAEIAN, ALI KHADEMIAN, DAVID SHINER, University of North Texas — Measurements on the fine structure of the 2P state of the helium atom show good agreement, 0.22(30) kHz, between the most recent theory (complete mo$^2$ evaluation with 0.02 kHz numerical uncertainty) and experiment. Among other things, this result could be used to give a value for the fine structure constant alpha with a 5 ppb uncertainty. However, some of the uncalculated mo$^8$ terms (those with large Z scaling), might contribute as much as 1.2 kHz, limiting the precision and thus calling for further theoretical work. For application to a precision alpha determination, an order of magnitude experimental improvement is desirable, given the electron g factor (0.4 ppb) and photon recoil (0.7 ppb) uncertainties. To this end we are currently addressing a major source of experimental uncertainty in our previous measurements by incorporating a convenient and reliable tunable laser frequency selector. An approach using a fiber grating and fiber circulator will be discussed.

1Supported by NSF grant PHY-1068868

D1.00138 Progress towards a new microwave measurement of the hydrogen n=2 Lamb shift: a measurement of the proton charge radius

A.C. VUTHA, N. BEZGINOV, I. FERCHICH, M.C. GEORGE, V. ISAAC, C.H. STORRY, A.S. WEATHERBEE, M. WEELE, E.A. HESSELS, York University — We propose to make a more precise measurement of the atomic hydrogen n=2 Lamb shift using the Ramsey method of separated oscillatory fields. This new measurement (with an anticipated uncertainty of 2 kHz – 5 times more accurate than the 1981 measurement of Lunde and Pipkin), along with existing precise atomic theory calculations, will allow for a new determination of the proton charge radius to an accuracy of 0.6 percent. The measurement will shed light on the 5$sigma$ discrepancy between proton radius recently obtained from muonic hydrogen [Pohl, et al, Nature 466, 213 (2010)] and the CODATA value.

This work is supported by NSERC, CRC and CFR of Canada.

D1.00139 Atomic properties of Ra for a future EDM measurement

Z. ZUHRIANDA, MARIANNA SAFRONOVA, University of Delaware, SERGEY PORSEV, University of Delaware and Petersburg Nuclear Physics Institute, MIKHAIL KOZLOV, Petersburg Nuclear Physics Institute — Searches for non-zero permanent electric-dipole moments (EDM) of particles, atoms, and molecules represent remarkable opportunity to probe new physics beyond the standard model. The EDMs arise from the violations of both parity and time-reversal invariance. Atomic EDMs caused by the nuclear parity and time invariance violating effects are enhanced in certain diamagnetic atoms, such as $^{199}\text{Hg}$ and $^{225}\text{Ra}$. For the latter, there is additional enhancement due to close states of opposite parity and the large nuclear charge Z [Dzuba et al., PRA 61, 062509 (2000)]. The search for EDM in $^{225}\text{Ra}$ is presently underway [Holt et al., Nucl. Phys. A 844, 53c (2010)]. Few atomic properties of Ra are experimentally known. In this work, we carry out a systematic study of Ra atomic properties of interest to the EDM search using recently developed relativistic ab initio method [Safronova et. al, PRA 80, 012516 (2009)] that allows to accurately treat correlation corrections in atoms with a few valence electrons. This method combines the coupled-cluster method, that yielded excellent results for monovalent systems, with the configuration-interaction approach. We have calculated energy levels, electric-dipole matrix elements, lifetimes, hyperfine constants, and polarizabilities.

1NSF and RFBR

D1.00140 ABSTRACT WITHDRAWN —

D1.00141 Development of 171Yb optical lattice clock at KRISS

JONGCHUL MUN, CHANG YONG PARK, DAI-HYUK YU, WON-KYU LEE, SANG EON PARK, TAEG YONG KWON, SANG-BUM LEE, KRISS — We measured the absolute frequency of the optical clock transition 150 (F = 1/2) - 3P0 (F = 1/2) of 171Yb atoms confined in a one-dimensional optical lattice and it was determined to be 518 295 836 590 865.7 (9.2) Hz. The measured frequency was calibrated to the Coordinated Universal Time (UTC) by using an optical frequency comb of which frequency was phase-locked to a hydrogen maser as a flywheel oscillator traceable to the UTC. The magic wavelength was also measured as 394 798.48 (79) GHz. The results are in good agreement with two previous measurements of other institutes within the specified uncertainty of this work.

D1.00142 Molecular Spectroscopy by Coherent Motion Detection

YEN-WEI LIN, BRIAN ODOM, Department of Physics and Astronomy, Northwestern University, Evanston, IL 60208 — We are currently constructing an experiment to perform spectroscopy on single trapped molecular ions. A silicon monoxide molecular ion (SiO$^+$) will be co-trapped with a barium ion in a linear Paul trap. The barium ion is laser-cooled and sympathetically cools the molecular ion; rotational cooling of SiO$^+$ will be accomplished by P-branch optical pumping on the B-X electronic transition. The spectroscopy result of the molecular ion is mapped to the barium ion through a state-dependent coherent motional state excitation. We are particularly interested in probing rotational (microwave) or vibrational (infrared) transitions sensitive to a time-varying electron-to-proton mass ratio.
D1.00143 Michelson-Morley with a Birefringent Cavity, FRANCISCO J. MONSALVE, MICHAEL HOHENSEE, HOLGER MÜLLER, Physics Department, University of California, Berkeley — We report on the progress of a birefringent cavity test of the isotropy of the speed of light. Previous experimental tests have constructed anisotropies in the speed of light at the level of parts in $10^{-17}$ [1-2]. These experiments search for frame-dependent variations in the resonant frequencies of two orthogonally mounted optical cavities. Uncorrelated fluctuations in the cavity lengths are a significant challenge for such experiments. Our experiment uses a single dielectric-filled cavity, and measures the difference in the resonant frequency of two orthogonally polarized modes. Anisotropies in the speed of light will manifest as a frame-dependent strain on the dielectric [3-4], giving rise to a frame-dependent variation in the cavity birefringence. By making the length of each cavity mode identical, we expect that our experiment will be less sensitive to thermal cavity fluctuations.


D1.00144 SPECIAL TOPICS (EXOTIC ATOMS AND MOLECULES; NONLINEAR DYNAMICS; NEW EXPERIMENTAL AND THEORETICAL METHODS; APPLICATIONS OF AMO SCIENCE) 1 —

D1.00145 Magnetic Shield Design and Processing, MICHAEL BULATOWICZ, Northrop Grumman — Magnetic shielding is a necessary component of many sensitive instruments including those required for a wide array of atomic and molecular physics experiments and inertial instruments, but what are the critical parameters influencing the performance of the shields? How can one achieve the greatest shielding factor in a limited physical space? What are the limits to shield performance? Shield thickness, size, number of layers, distance between layers, material, and so on all have influence on the performance. Magnetic permeability alone depends on incident magnetic flux density, magnetostriiction effects, shield material impurities, material microstructure, crystalline grain size, mechanical strain, skin depth effects, and shield size and thickness. Magnetic noise produced by the shields is a function of magnetic permeability, temperature, and shield thickness, electrical resistivity, and size. These phenomena and the ability to control the influence of these parameters for a given instrument will be discussed. A set of design and processing guidelines and generalized equations will be presented for the purposes of optimizing the magnetic shielding design and thereby achieving the highest possible performance from a magnetically shielded instrument.

D1.00146 There is no speed barrier in the universe, FLORENTIN SMARANDACHE, University of New Mexico — In a 1972 paper we have advanced the hypothesis that there is no speed barrier in the universe and one can construct any speed from zero to infinity. We considered that the superluminal speeds do not violate the causality principle, do not produce time traveling and it is not needed infinite energy in order for a particle to travel at a speed greater than the speed of light. On September 22, 2011, Dr. Antonio Ereditato and his team at CERN has experimentally found the neutrino particles traveling at a speed greater than c, partially confirming this hypothesis.

D1.00147 Economical Nanoactuator Alternatives to Lead Zirconium Titanate, JIN WANG, GABE ELGHOUL, STEPHEN PETERS, University of Michigan Dearborn — This paper describes using inexpensive commercially available ceramic capacitors as a substitute for the lead containing and relatively expensive PZT based nano actuators. A sample PZT actuator is compared with actuators made from both XSR and YSV type ceramic dielectric capacitors using white light interferometry and a spectrometer. This work is useful in that it can provide nano-motion capability to budget constrained undergraduate and graduate level research laboratories. Additionally, unlike the PZT material the alternative ceramic materials do not contain lead which is needed to create products compliant with the European RoHs (Restriction On Hazardous Substances) initiative.

D1.00148 Multi-Beam Shuttering, Pulsing, and Intensity Control Using Liquid Crystals, SARAH BICKMAN, STEPHANIE MCMAHON, JEREMY SHUGRUE, BENJAMIN LUEY, JUAN PINO, SCOTT ROMMEL, MICHAEL ANDERSON, Vescent Photonics — To date, most experiments involving lasers have required space-consuming acousto-optic modulators and mechanical shutters to control the intensity of laser beams used in cold-atom experiments. To support emerging cold-atom sensors such as atomic clocks, inertial navigation units, and magnetometers these complex electro optics must be replaced with compact components that can operate in a field environment. Using liquid-crystal spatial light modulators we have demonstrated an optical component that separates a single laser source into multiple beam paths that can be independently controlled. Each beam can be shuttered with 70 dB of contrast, pulsed down to 12 us, and intensity stabilized with 150 kHz loop bandwidth. These devices operate in the wavelength range of 630-1000 nm. We will present current designs and results of the liquid crystal multi-beam shutter and how it enables complete and compact cold-atom laser systems the size of a paperback novel.

D1.00149 Refractive index sensing of turbid media by differentiation of the reflectance profile: Analysis of error1. MIAO DONG, KASHIKA GOYAL, DONALD KANE, BRADLEY WORTH, LALIT BALI, SAMIR BALI, Department of Physics, Miami University — Refractive index detection typically consists of a measurement of the reflectance of light from the sample surface for various angles of incidence, and determining the critical angle for total internal reflection (TIR). A commonly used technique for locating the critical angle is to differentiate the angular reflectance profile with respect to the incidence angle, and look for the point of maximum change of slope. For turbid media this differentiation technique leads to errors in refractive index measurement, which need to be accurately estimated. We show that previous attempts by other workers to calculate the error using traditional Fresnel theory yield an expression that is impossible to physically justify, and hence must be incorrect. We calculate the error using a recent model of TIR in turbid media by Calhoun, et al. (Opt. Lett. 35, 1224 (2010)) which departs from traditional Fresnel theory, and show that this error varies with turbidity in an expected manner. Important differences from previous work relying on traditional Fresnel theory are revealed with regard to the size of error as a function of turbidity, and the choice of polarization for minimizing error.

1Financial support from Petroleum Research Fund and Dillon-Kane LLC is gratefully acknowledged.

D1.00150 Theoretical description of transverse measurements of polarization in optically-pumped Rb vapor cells, JOAN DREILING, University of Nebraska-Lincoln, DALE TUPA, Los Alamos National Laboratory, ERIC NORRGARD, TIMOTHY GAY, University of Nebraska-Lincoln — In optical pumping of alkali-metal vapors, the polarization of the atoms is typically determined by probing along the entire length of the pumping beam, resulting in an averaged value of polarization over the length of the cell. Such measurements do not give any information about spatial variations of the polarization along the pump beam axis. Using a D1 probe beam oriented perpendicular to the pumping beam, we have demonstrated a heuristic method for determining the polarization along the pump beam’s axis. Adapting a previously developed theory [1], we provide an analysis of the experiment which explains why this method works. The model includes the effects of Rb density, buffer gas pressure, and pump detuning.

D1.00151 A focused CO$_2$ laser beam for phase contrast electron microscopy, MICHELLE XU, ERIN SOHR, HOLGER MUELLER, University of California, Berkeley — Phase contrast electron microscopy, in analogy to the Zernike microscopy, enables imaging of previously elusive organic or nonorganic specimens [1]. While existing physical phase plates degrade due to electron charging effects, a laser phase plate (LPP) utilizes the ponderomotive potential to shift the electron phase and should offer reusability and improved longevity. The un-diffracted electrons travel through the laser beam (150 W, Apollo 150 CO$_2$ laser), which produces the ponderomotive potential. To increase the phase shift with the same amount of laser power, we use axicon lenses to generate Laguerre-Gaussian mode, which can be optimally focused by the parabolic mirror. To further enhance the focal intensity, we place a partial reflector at the opening of the parabolic mirror to form an optical resonator. This scheme will offer $\pi$/2 electron phase shift [1], and will enable phase contrast imaging. We present experimental demonstration of the parabolic-mirror cavity (the LPP) and the resulting electron phase shift.


D1.00152 ABSTRACT WITHDRAWN

D1.00153 Worldline Method for Electromagnetic Casimir Energies, JONATHAN MACKRORY, University of Oregon, Department of Physics, TANMOY BHATTACHARYA, Santa Fe Institute, DANIEL STECK, University of Oregon, Department of Physics — We present our work on the generalization of the worldline method for calculating electromagnetic Casimir energies. Previously, this method has been restricted to calculations for a scalar field. Our work calculates the Casimir energy due to dispersive, dielectric bodies with arbitrary geometries. The worldline method calculates the energy by generating an ensemble of closed space-time paths via a Monte Carlo algorithm, and then summing up the contributions from the dielectric along each path. We will present our work on handling the convergence issues associated with the path integral, and some preliminary results comparing the method with other algorithms and known test cases.

D1.00154 Characterization of a green astro-comb using a Fourier Transform Spectrometer, ALEXANDER GLENDAY, CHIN-HAO LI, Harvard-Smithsonian, MATTHEW WEBBER, Northeastern University, NICHOLAS LANGELLIER, GABOR FURESZ, Harvard-Smithsonian, GUOJIONG CHANG, LI-JIN CHEN, HUNG-WEN CHEN, JINKANG LIM, FRANZ KAERTNER, Massachusetts Institute of Technology, DAVID PHILLIPS, ANDREW SZENTGYORGYI, RONALD WALSORTH, Harvard-Smithsonian — Searches for Earth-like exoplanets using precision stellar spectroscopy must be unprecedented. The accuracy of an astro-comb relies on high-quality suppression of undesired comb lines by the FPC. Here we present a characterization of a green astro-comb using a high-resolution Fourier Transform Spectrometer (FTS) constructed in our laboratory. The FTS has an unapodized resolution of 125 kHz, which enables high resolution measurements of our 1 GHz repetition rate laser frequency comb after it has been filtered into a 20 GHz astro-comb. FTS measurements of the green astro-comb will reveal any systematic defects in our filtering process and help determine the ultimate accuracy of the astro-comb as a wavelength reference.

D1.00155 Evaluation of the Sensitivity Limits of Chip-scale Atomic Magnetometers, JIAYAN DAI, University of Colorado at Boulder and National Institute of Standards and Technology, RAHUL MHASKAR, ETHAN PRATT, W. CLARK GRIFFITH, AMBER PAGE, SVENJA KNAPPE, JOHN KITCHING, National Institute of Standards and Technology — Despite the fact that atomic DC magnetometers have reached impressive sensitivities, POST, SVENJA KNAPPE, JOHN KITCHING, National Institute of Standards and Technology, RAHUL MHASKAR, ETHAN PRATT, W. CLARK GRIFFITH, AMBER PAGE, and our recent demonstration of a synchronously pumped magnetometer in which the vapor cell is coupled to the pump and probe optics solely by optical fibers. Tests of this device at finite field ($\sim 10$ mG) and at Earth’s field will be presented. Here describe a synchronously pumped magnetometer in which the vapor cell is coupled to the pump and probe optics solely by optical fibers. Tests of this device at finite field ($\sim 10$ mG) and at Earth’s field will be presented.

D1.00156 A compact fiberized alkali-vapor atomic magnetometer, ELENA ZHIVUN, BRIAN PATTON, Department of Physics, UC Berkeley, CHRIS HOYDE, Southwest Sciences, Inc., DMITRY BUDKER, Department of Physics, UC Berkeley — Alkali-vapor atomic magnetometers are among the world’s most sensitive magnetic field measuring devices, with demonstrated precisions [1] better than $1T/\sqrt{Hz}$ when operated in the SERF regime. All-optical magnetometers operating at finite fields require synchronous optical pumping to reinforce the precessing atomic spin polarization. Here describe a synchronously pumped magnetic field using the laser beam for phase contrast electron microscopy, MICHELLE XU, ERIN SOHR, HOLGER MUELLER, University of California, Berkeley — Phase contrast electron microscopy, in analogy to the Zernike microscopy, enables imaging of previously elusive organic or nonorganic specimens [1]. While existing physical phase plates degrade due to electron charging effects, a laser phase plate (LPP) utilizes the ponderomotive potential to shift the electron phase and should offer reusability and improved longevity. The un-diffracted electrons travel through the laser beam (150 W, Apollo 150 CO$_2$ laser), which produces the ponderomotive potential. To increase the phase shift with the same amount of laser power, we use axicon lenses to generate Laguerre-Gaussian mode, which can be optimally focused by the parabolic mirror. To further enhance the focal intensity, we place a partial reflector at the opening of the parabolic mirror to form an optical resonator. This scheme will offer $\pi$/2 electron phase shift [1], and will enable phase contrast imaging. We present experimental demonstration of the parabolic-mirror cavity (the LPP) and the resulting electron phase shift.


D1.00157 Powerful low-cost laser lab instrumentation using 32-bit microcontrollers and an Android tablet interface, EDWARD EYLER, University of Connecticut — Recently, our laboratory has developed several homemade instruments based on 16-bit microcontrollers. Since then, powerful 32-bit microcontrollers have become available, often including host-mode USB interfaces. Concurrently, Android-based tablets with high-resolution graphical displays have become commonplace. With appropriate programming, some tablets can communicate via USB, allowing them to serve as bidirectional touch-screen interfaces. I will describe ramp and timing sequence generators with resolution up to 12.5 ns that can be constructed with very little cost or effort, by making minor additions to commercial development boards. With these instruments, a graphical tablet interface is used mainly for parameter entry, but it is even more useful as a display interface for applications such as laser frequency locking [1] and signal monitoring. To minimize programming for the Android devices, my approach is to develop just a few general-purpose “apps” that can operate a wide range of instruments. When the USB interface is connected, the microcontroller informs the tablet of its display requirements. This arrangement can eliminate the need for dedicated computers, custom data entry units, or oscilloscopes.

[1] This work is supported in part by the National Science Foundation

Wednesday, June 6, 2012 8:00AM - 10:00AM –
Session G1 Invited Session: Disorder in Cold Atoms Systems
Grand Ballroom BCD - Chair: Steven Rolston, University of Maryland
Extended states in these systems are directly relevant to disordered quantum gases, which are confined in traps and we propose a realistic scheme to observe the coexistence of localized and extended states in a disordered trap. 

We observe three-dimensional AL of noninteracting ultracold matter by allowing a spin-polarized atomic Fermi gas to expand into a disordered potential. A recent experiment [1], where the authors used a disordered potential produced by a combination of a lattice and a quasidisorder from an incommensurate lattice, shows that the transport properties of the system are consistent with recent predictions for interacting bosons in one dimension, illustrating the important role of correlations in disordered atomic systems.

1 We acknowledge support from the DARPA OLE program, the NSF, and the ONR.

Three-Dimensional Anderson Localization of Ultracold Matter

Three-Dimensional Anderson Localization of Ultracold Matter

Simulating quantum transport with atoms and light

9:30AM G1.00004 Simulating quantum transport with atoms and light, VINCENT JOSSE, LP2N - IOGS

— The transport of quantum particles in non ideal material media (eg the conduction of electrons in an imperfect crystal) is strongly affected by scattering from imperfections of the medium. Even for a weak disorder, semi-classical theories, such as those based on the Boltzmann equation for matter-waves scattering from the imperfections, often fail to describe transport properties and full quantum approaches are necessary. The properties of the quantum systems are of fundamental interest as they show intriguing and non-intuitive phenomena that are not yet fully understood such as Anderson localization, percolation, disorder-driven quantum phase transitions and the corresponding Bose-glass or spin-glass phases. Understanding quantum transport in amorphous solids is one of the main issues in this context, related to electric and thermal conductivities. Ultracold atomic gases can now be considered to revisit the problem of quantum conductivity and quantum transport under unique control possibilities. Dilute atomic Bose-Einstein condensates (BEC) and degenerate Fermi gases (DFG) are produced routinely taking advantage of the recent progress in cooling and trapping of neutral atoms. Transport has been widely investigated in controlled potentials with no defects, for instance periodic potentials (optical lattices). Controlled disordered potentials can also be produced with various techniques such as the use of magnetic traps designed on atomic chips with rough wires, the use of localized impurity atoms, the use of radio-frequency fields or the use of optical potentials. This recent lead to the observation of the Anderson Localization of a BEC in 1D and 3D, and the study of diffusion properties during matter-wave transport.

2 In collaboration with Philippe Bouyer, LP2N - IOGS.

Wednesday, June 6, 2012 8:00AM - 10:00AM – Session G2 Synthetic Gauge Fields for Ultracold Systems

Grand Ballroom GF - Chair: Ian Spielman, JQI, NIST, and University of Maryland

Superfluid Hall effect in a Bose-Einstein condensate

8:00AM G2.00001 Superfluid Hall effect in a Bose-Einstein condensate, LINDSAY J. LEBLANC, KARINA JIMENEZ-GARCIA, ROSS A. WILLIAMS, MATTHEW C. BEELER, ABIGAIL R. PERRY, WILLIAM D. PHILLIPS, IAN B. SPIELMAN, Joint Quantum Institute, NIST and University of Maryland — In condensed matter physics, measurement techniques exploiting the Hall effect are widely used to explore the internal properties of solids, ranging from charge-carrier concentrations in semiconductors to the quantum Hall effects in two-dimensional electron gases. While Hall physics is generally associated with the reaction of charged particles to a magnetic field, we observed a superfluid Hall effect in a BEC of neutral $^{87}$Rb atoms subjected to an artificial magnetic field $B^*$. To probe the BEC’s properties, we generated an alternating atomic current and measured the cloud’s dynamics as a function of $B^*$. When the artificial field is present, an effective Lorentz force acts on the atoms and the current is deflected in the direction transverse to the usual hydrodynamic flow, indicating a Hall effect. The good quantitative agreement between our measurements and a superfluid hydrodynamic model indicates that this Hall effect is associated with the BEC’s irrotational superfluidity. By extending the Hall measurement technique to the realm of neutral-atom experiments, we establish this talk as a valuable probe for exploring the internal or many-body properties of ultracold gas systems.

8:12AM G2.00002 Exotic 3D Spin-Orbit Couplings, BRANDON ANDERSON, Joint Quantum Institute, NIST, and University of Maryland, GEDMINAS JUZELJUNAS, Institute of Theoretical Physics and Astronomy of Vilnius University, VICTOR GALITSKI, Joint Quantum Institute and Physics Department, University of Maryland, IAN SPIELMAN, Joint Quantum Institute, NIST, and University of Maryland — We describe a scheme for creating an isotropic three-dimensional spin-orbit coupling, dubbed Weyl spin-orbit coupling, in systems of ultracold atoms. This coupling is induced by Raman transitions that link four internal atomic states with a tetrahedral geometry. This spin-orbit coupling gives rise to a Dirac point that is robust against environmental perturbations. We then propose a general procedure for generating exotic three-dimensional spin-orbit couplings with degenerate ground states on more complex manifolds. The procedure is applied to produce a spin-orbit coupling with a toroidal ground state manifold. Finally, we discuss the many-body implications of the exotic spin-orbit couplings.

8:24AM G2.00003 Topological excitations of a spinor BEC by inhomogenous magnetic fields, RYAN OLFF, G. EDWARD MARTI, GABRIEL DUNN, DAN STAMPER-KURNN, University of California, Berkeley — Inhomogenous magnetic fields, such as those produced by the common spherical quadrupole configuration, couple spin and motional degrees of freedom in neutral spinor Bose-Einstein condensates, in direct analogy to the coupling of a magnetic field to an electric charge. Such gauge fields for neutral atoms have been of interest due to their ability to create interesting topological states, such as vortices, quantum hall and spin quantum hall states, and skyrmions. In this talk we report on the use of time-varying inhomogenous magnetic fields to create topological excitations in $F=1$ $^{87}$Rb confined to an optical trap.
8:36AM G2.00004 2D and 3D topological states of cold atoms with synthetic gauge fields1. CONGJUN WU, YI LI, Department of Physics, University of California, San Diego, XIANGFA ZHOU, Key Laboratory of Quantum Information, University of Science and Technology of China, CAS, Hefei, Anhui 230026, People’s Republic of China — We found that the synthetic gauge fields from the light-atom interaction combined with harmonic trapping potential give rise to exotic topological band structure in both 2D and 3D. Landau-level like quantizations appear with the full 2D and 3D rotational symmetry and time-reversal symmetry. Inside each band, states are labeled by their angular momenta over which energy dispersions are strongly suppressed by spin-orbit coupling to nearly flat. The radial quantization generates the energy gap between neighboring bands at the order of the harmonic frequency. Helical edge or surface states appear on open boundaries characterized by the Z2 index. These Hamiltonians can be viewed from the dimensional reduction of the high quantum number states in 3D and 4D flat spaces.

1The authors thank the support from NSF, and AFOSR

8:48AM G2.00005 Effect of synthetic magnetic fields on quasi-2D gases of bosons , MATTHEW BEELER, KARINA JIMENEZ-GARCIA, LINDSAY LÉBLANC, ABIGAIL PERRY, ROSS WILLIAMS, IAN SPIELMAN, Joint Quantum Institute, NIST and University of Maryland — An ultra-cold gas of atoms can realize many different model Hamiltonians. When tightly confined in one spatial dimension, the gas can become effectively 2D. At a critical temperature, a quasi-2D Bose gas undergoes a Berezinski-Kosterlitz-Thouless (BKT) phase transition to a superfluid as thermally excited pairs of vortices with opposite circulation bind together [1]. In general, a superfluid responds to the presence of a synthetic magnetic field with the formation of vortices [2], expected to all have the same circulation direction. These vortices induced by the synthetic magnetic field should have an effect on the microscopic mechanism behind the BKT phase transition, which may alter the properties of the quasi-2D Bose gas.


9:00AM G2.00006 Contact of dilute atomic Fermi gases with spin-orbit couplings , ZHENHUA YU, Institute for Advanced Study, Tsinghua University — We study the contact of three dimensional spin half dilute atomic Fermi gases with spin-orbit couplings. The interatomic interaction is modeled by the contact pseudopotential. In the high temperature limit, we derive the expression for the second virial expansion of the thermodynamic potential via the ladder diagrams. When the spin-orbit couplings are small, we show that the contact between the fermions increases as the fourth power of the couplings. At zero temperature, we consider the cases where there are symmetric spin-orbit couplings in two or three dimensions. In the dilute limit, the system consists of condensed bosonic molecules; we find that the contact also becomes bigger compared to that in the absence of spin-orbit couplings. Our results indicate that generally spin-orbit couplings enhance the contact of the Fermi gases. Such enhancement can be measured via photoassociation.

9:12AM G2.00007 Spin-orbit coupled Fermi liquid theory with magnetic dipolar interaction , YI LI, CONGJUN WU, Department of Physics, University of California, San Diego — We investigate the Fermi liquid properties of the ultra-cold magnetic dipolar Fermi gases in the simplest case of two-component. The magnetic dipolar interaction is invariant under the simultaneous spin-orbit rotation, but not under either LI, CONGJUN WU, Department of Physics, University of California, San Diego — We investigate the Fermi liquid properties of the ultra-cold magnetic dipolar Fermi gases in the simplest case of two-component. The magnetic dipolar interaction is invariant under the simultaneous spin-orbit rotation, but not under either

9:36AM G2.00009 Rashba spin-orbit coupled atomic Fermi gases1. LEI JIANG, Department of Physics and Astronomy, and Rice Quantum Institute, Rice University, Houston, TX, XIA-JI LIU, HUI HU, ARC Centre of Excellence for Quantum-Atom Optics, Swinburne University of Technology, Melbourne, Australia, HAN PU, Department of Physics and Astronomy, and Rice Quantum Institute, Rice University, Houston, TX — We investigate theoretically BEC-BCS crossover physics in the presence of a Rashba spin-orbit coupling in a system of two-component Fermi gas with and without a Zeeman field that breaks the population balance between the two components. A new bound state (Rashba pair) emerges because of the spin-orbit interaction. We study the properties of Rashba pairs using a standard pair fluctuation theory. At zero temperature, the Rashba pairs condense into a macroscopic mixed spin state. We discuss in detail the experimental signatures for observing the condensation of Rashba pairs by calculating various physical observables which characterize the properties of the system and can be measured in experiment.

1This project is supported by the NSF, the Welch Foundation and the ARC Discovery Projects.

9:48AM G2.00010 Hamiltonian monodromy , CHEN CHEN, MEGAN IVORY, AUBIN SETH, JOHN DELOS, College of William and Mary — We say that a system exhibits monodromy if we take the system around a closed loop in its spectrum space, and we find that the system does not come back to its original state. We report a method for experimental realization of a newly discovered dynamical manifestation of monodromy by investigating the behavior of atoms in a trap. The trapping potential has long range attraction to and short range repulsion from the center. Calculations include two parts. First, we consider atoms as classical particles for which we can choose any desired set of initial conditions. As was shown previously for different systems, when we take the system around a monodromy circuit, a loop of initial conditions evolves into a topologically different loop. Second, we incorporate the limitations that would appear in experimental implementation. The atoms have a range of initial angles, initial angular momenta, and initial energies. Our work shows how real atoms can be driven by real forces around a monodromy circuit, and thereby shows how one can observe dynamical monodromy in a laboratory. Finally, we extend classical dynamical monodromy to quantum dynamical monodromy by examining wave function evolution under comparable conditions.

Wednesday, June 6, 2012 8:00AM - 10:00AM — Session G3 Invited Session: Line Broadening Grand Ballroom E - Chair: Arati Dasgupta, Naval Research Laboratory
8:00AM G3.00001 Line Broadening in White Dwarf Photospheres, D.E. WINGET, Department of Astronomy and McDonald Observatory, University of Texas — White dwarfs are the simplest stars with the simplest surface chemical compositions known. Spectroscopically we detect only hydrogen in surfaces of the vast majority of these stars. The remainder are of various types, including stars with surfaces of nearly pure helium and some apparently massive stars with carbon and oxygen at the photosphere. We will examine the potential offered by the white dwarf stars in the context of both astrophysics and physics. This potential includes studying cosmochronology—establishing the age and evolutionary history of our galaxy and an independent lower limit on the age of the universe, constraining the properties of axions and WIMPs in the context of dark matter models, constraining dark energy by establishing the properties of the massive progenitors of type Ia supernovae, studying nucleosynthesis from their internal composition structure, and crystallization in dense Coulomb plasmas, among many others. Realizing this tremendous scientific potential depends on the determination of two boundary conditions for each star: the surface gravity and effective temperature. To do this, we must establish the photospheric plasma conditions, density and temperature, using observations of the stellar absorption spectra. Our understanding of line broadening appears to be an obstacle, at present. We will discuss the evidence for past theoretical inadequacies in line broadening theory and the hope for recent and future calculations. We will discuss how the experiments underway on the Z-facility at Sandia National Laboratories—where we can create macroscopic uniform plasmas under white dwarf photospheric conditions—will provide the benchmarks for improving our understanding of line broadening under white dwarf photospheric plasma conditions. These experiments will guide future theory and improve our understanding of the white dwarf stars and, through them, the contents and evolution of the cosmos.

8:30AM G3.00002 Broadening of Hydrogenic Spectral Lines in Magnetized Plasmas: Diagnostic Applications, EUGENIE OKS, Auburn University — In diagnostics based on the broadening of spectral lines in plasmas, magnetic fields are important only if their strength is relatively high—compete with the Stark and Doppler broadenings. Relevant examples are plasmas produced by ultrashort, high intensity lasers and edge plasma magnetic fusion experiments. The focus of this invited talk is on hydrogenic spectral lines. This is because the generally complicated physics of the Stark-Zeeman broadening can be best understood and used in practice for spectral lines of one-electron systems: hydrogen atoms and hydrogen-like ions. Besides, this subject is also theoretically important for two reasons. First, it deals with a deeply fundamental problem of the simplest, two-particle bound Coulomb system immersed in a multi-particle Coulomb system of free charges (plasma) exhibiting long-range interactions. Second, due to the fact that a bound two-particle Coulomb system possesses a higher algebraic symmetry than its geometrical symmetry, sophisticated analytical advances can be made into the problem of the broadening of spectral lines of such a system in a plasma, thus yielding a profound physical insight and leading to innovative diagnostic applications.

9:00AM G3.00003 A new method for line-shape modeling of hydrogen-like and Rydberg transitions in plasma, EVDENY STAMBULCHIK, Weizmann Institute of Science — Calculations of line shapes of hydrogen and hydrogen-like transitions (including Rydberg ones) are important for many topics of plasma physics and astrophysics. However, the Stark effect of the radiative transitions originating from high-n levels is rather complex, making the detailed calculations of their spectral structure very cumbersome. Surprisingly, the complex structure of such transitions can be approximated, under certain assumptions, with a quasi-contiguous (QC) rectangular shape. This formed the basis of an analytical method for the calculation of line broadening [1], resulting in a simple expression for the full width at half-maximum of the Stark line broadening in plasma. Although the method is especially suitable for transitions with ∆n ≫ 1, it describes rather well even first members of the spectroscopic series with ∆n as low as 2. Recently, the QC method was extended [2] to analytical calculations of line shapes (not mere line widths) in plasmas. To this end, we employed a formulation [3] of the frequency fluctuation model. Accurate computer simulations [4] as well as comparison with experimental data, where available, were used to verify the validity of the method. Applications of the method to a range of physical problems are shown.


9:30AM G3.00004 Collisional-radiative analysis of neutral beam spectra in fusion plasmas, YURI RALCHENKO, National Institute of Standards and Technology — Powerful beams of neutral particles are extensively used in fusion devices, such as tokamaks and stellarators, to heat and diagnose magnetically confined plasmas. The spectral lines originating from the excited states of a neutral beam permit valuable information on plasma fields, particle temperatures and densities, and other parameters. I will present the recently developed collisional-radiative (CR) model for m-resolved parabolic states of hydrogen which has been successfully used to explain motional Stark effect (MSE) spectra from tokamak plasmas [1]. A new method for calculation of collisional cross sections between parabolic states is developed and used to compute the required atomic data. It is shown that the σ- and π-component intensities under typical magnetic fusion conditions cannot be described by statistical (Boltzmann) distribution and therefore require a complete CR analysis. I will also discuss non-statistical behavior of parabolic state populations in a wide range of parameters including those of the ITER tokamak. The field-induced ionization of the high excited states is shown to be a strong uncompensated depopulation channel responsible for deviations from the Boltzmann distribution. 

2 E. Delabie et al., PPCF 52, 125008 (2010).

Wednesday, June 6, 2012 8:00AM - 10:00AM — Session G4 Focus Session: Progress in Attosecond Physics Garden 1-2 - Chair: Louis DiMauro, Ohio State University

8:00AM G4.00001 Time-resolved photoemission by attosecond streaking1, STEFAN NAGELE, Institute for Theoretical Physics, Vienna University of Technology — With the advent of sub-femtosecond ultrashort light pulses novel pathways have opened up for investigating time-resolved electronic processes on the attosecond scale. One of the most fundamental techniques is attosecond streaking which enables time domain studies of photoionization for atoms, molecules, and solids and provides unprecedented information on the release time of photoelectrons. The challenge in interpreting the obtained time delays lies in disentangling the intrinsic time shifts one is interested in and the additional measurement-induced apparent delays caused by the probing infrared (IR) field in the streaking setup. In this talk, these issues will be addressed with the help of a few examples. On the one-electron level we identify effects of the dressing IR field on the extracted streaking delays in the entrance (initial state) and in the exit (continuum) channel for atomic photoemission. On the multi-electron level we study the effect of electron correlations on the time delays and explore their influence in the presence of the probing streaking field. As a prototypical two-electron system we study helium which exhibits rich many-electron effects. We quantify all the contributions to the streaking time shifts with attosecond precision and provide benchmarks for future experiments.

9:00AM G4.00003 Generation and characterization of broadband isolated attosecond pulse\(^1\). Qi ZHANG, KUN ZHAO, MICHAEL CHINI, YI WU, College of Optics and Photonics and Department of Physics, University of Central Florida, XIAOWEI WANG, National University of Defense of China, Department of Physics, ZHENGHU CHANG, College of Optics and Photonics and Department of Physics, University of Central Florida — A 7.5 fs, 780 nm infrared laser was tightly focused on a Ne gas target to generate an XUV supercontinuum spectrum by applying the Double Optical Gating (DOPG) method. This supercontinuum reaches a cutoff at 120 eV photon energy. The XUV pulse was filtered by a Zr filter to compensate the intrinsic chirp from the XUV generation. The spectrum after the filter supports an isolated pulse as short as 60 as centered at 80 eV photon energy. The spectral phase of the XUV pulse was extracted from the measured attosecond streaking trace by the Phase Retrieval by Omega Oscillation Filtering (PROOF).

\(^1\)This work is supported by the U. S. Army Research Office, and by the Chemical Sciences, Geosciences, and Bioscience Division, U.S. Department of Energy.

9:12AM G4.00004 Absorption of Attosecond Pulses by Laser-dressed Atoms, SHAOHAO CHEN\(^2\), METTE B. GAARDE, KENNETH J. SCHAFTER, Department of Physics and Astronomy, Louisiana State University, Baton Rouge, LA 70803, USA — We study the transient absorption of attosecond pulses by IR-laser-dressed He atoms using both single-atom and macroscopic methods [1]. In the case of an attosecond pulse train, we report for the first time a quarter-cycle modulation (mixed with the well-known half-cycle modulation [2-4]) in the absorption as a function of time delay, indicating that high-order couplings between the harmonics can be obtained by modifying parameters of laser and gas medium. We also find that the absorption probability is tied to resonant laser-dressed atomic states, and the timing of absorption is sensitive to laser parameters and reshaping of the attosecond pulses. In the case of a single attosecond pulse, we exhibit the attosecond time-scale evolution of the absorption probability as well as that of the AC Stark shift [5]. We find a light-induced state formed by a resonant two-photon absorption process. We also find electron wavepacket interference between two quantum path ways into the continuum (direct and via bound states) [6].


9:24AM G4.00005 Nanoplasmic light field synthesis for isolated attosecond pulse generation, JOHANNES FEIST, ITAMP, Harvard-Smithsonian Center for Astrophysics, M.T. HOMER REID, Research Laboratory of Electronics, MIT, MATTHIAS F. KLING, J. R. Macdonald Laboratory, Kansas State University — Nanometer-scale metallic structures can lead to a strong concentration of optical fields due to plasmon resonances. This can be used to generate very strong electric fields even with moderate driving laser intensities, enabling high-harmonic generation (HHG) at much lower intensities than usually required. The reduced need for amplifying stages in the driving laser then allows for high repetition rates in the MHz range. However, the sources demonstrated up to now do not produce ultrashort (attosecond) pulses, in part because the temporal response of a plasmon resonance stretches and distorts the incoming laser pulse. We here describe a general approach for generating isolated attosecond pulses using nanoplasmically enhanced fields. We show that for practically useful structures, pulse shaping of the incoming pulse can compensate for the distortion and temporarily confine the plasmon-enhanced field response. Coherent control techniques for pulse shaping, which are applicable at the low required input intensities, can then be used to generate isolated attosecond pulses even if the response of the plasmonic structure is not known a priori.

9:36AM G4.00006 Asymmetries in Production of He\(^+(n=2)\) with an Intense Few-Cycle Attosecond Pulse\(^1\), JEAN MARCEL NGOKO DJIOKAP, The University of Nebraska-Lincoln, SUXING X. HU, The University of Rochester, ANTHONY F. STARACE, The University of Nebraska-Lincoln — By solving the two-active-electron time-dependent Schrödinger equation (in its full dimensionality) in an intense few-cycle attosecond pulse, we investigate the carrier-envelope-phase (CEP) induced asymmetries in the differential probability for ionization plus excitation of He to the He\(^+(n=2)\) states. Owing to the broad bandwidth of the intense pulse, substantial asymmetries in the differential probability for ionization of an electron along the positive and negative polarization direction of the pulse are found. Such asymmetry involves prominent interference between direct and indirect ionization pathways seen simultaneously in the partial photoelectron spectra. Electron correlations are probed by comparing projections of the wave packet onto the field-free highly correlated Jacobi matrix wave function [E. Fouboumo et al., Phys. Rev. A 74, 063409 (2006)] and uncorrelated Coulomb states. The CEP-effect found along the z-axis in the total asymmetry seems to be consistent with perturbation theory [E. A. Pronin et al., Phys. Rev. A 80, 063403 (2009)].

\(^1\)This work is supported in part by the U.S. Department of Energy, Office of Science, Division of Chemical Sciences, Geosciences, and Biosciences, under Grant No. DE-FG03-96ER14646.

9:48AM G4.00007 Monitoring Attosecond Electron Motion by High Order Harmonic Generation, ANDRE D. BANDRAUK, Canada Research Chair, Université de Sherbrooke, SCZEPAN CHELKOWSKI, Université de Sherbrooke — Pump-probe schemes are proposed from numerical solutions of Time Dependent Schroedinger Equations in nonBorn Oppenheimer (nonstatic nuclei) simulations of H\(^2+\) to measure and monitor electron motion in molecules. A weak few cycles XUV pump pulse is first used to create a coherent superposition of electron-nuclear wavepackets in bound and dissociative electronic states followed by a short intense 800 nm probe pulse which generates harmonics via ionization and recollission of electrons with the initial coherent electron-nuclear wavepacket [1]. We show that by varying the time delay between pump and probe on attosecond time scale induces large suppression of the harmonic signal with an attosecond time periodicity corresponding to the electronic time periodicities in the coherent wavepacket. The three step model of harmonic generation concomitant with the SPA approximation [2] are used to explain the periodic change of harmonic signal and incipient decoherence due to vanishing of nuclear function overlap between different electronic potentials populated in the coherent wave packet. The mechanism is further confirmed by a time-series analysis.

8:00AM G5.00001 Towards Bose-Einstein condensation of Erbium atoms, KIYOTAKA AIKAWA, ALBERT FRISCH, MICHAEL MARK, ALEXANDER RIETZLER, JOHANNES SCHINDLER, Inst. for Exp. Physics, Univ. Innsbruck, ERIK ZUPANIC, J. Stefan Institute and Inst. for Exp. Physics, Univ. Innsbruck, SIMON BAIER, Inst. for Exp. Physics, Univ. Innsbruck, RUDOLF GRIMM, IQOQI, Austrian Acad. of Sciences and Inst. for Exp. Physics, Univ. Innsbruck, FRANCESCA FERLAIMO, Inst. for Exp. Physics, Univ. Innsbruck — Ultracold dipolar gases offer a promising playground for exploring a wide variety of novel quantum phases as well as quantum magnetism. Recent advances in laser cooling technique have opened up a possibility to reach ultracold temperature with highly magnetic rare-earth atoms. Here, we present our results towards Bose-Einstein condensation of Erbium atoms. By using a broad transition at 401 nm for Zeeman slowing and a narrow transition at 583 nm for a magneto-optical trap (MOT), we obtained up to $3 \times 10^5$ atoms at a temperature of $15 \, \mu K$. Typically $1 \times 10^7$ atoms are directly loaded from a MOT into an optical dipole trap operating at 1064 nm. The results show that our approach gives a good starting condition for evaporative cooling.

8:12AM G5.00002 Novel bond order phase of dipolar fermions, SATYAN BHONGALE, George Mason University, LUDWIG MATHEY, Universitat Hamburg, SHAN-WEN TSAI, University of California, Riverside, CHARLES CLARK, NIST-Gaithersburg, ERHAI ZHAO, George Mason University — Cold atoms provide a promising platform to solve problems that, although computationally infeasible, are of immense importance to condensed matter physics and material science. Ultra-cold bosonic systems have been quite successful in emulating the Bose-Hubbard model. Experiments are now underway towards mapping out the unknown phase diagram of the Fermi-Hubbard model. Recent experimental advances in cooling dipolar gases to quantum degeneracy provide an unprecedented opportunity to engineer Hubbard-like models with long range interactions. Here we show that two new and exotic types of order emerge generically in dipolar fermion systems: bond order solids of $p$- and $d$-wave symmetry. Similar, but manifestly different, phases of two-dimensional correlated electronic systems have only recently been hypothesized. Our results suggest that these phases can be constructed flexibly with dipolar fermions, using currently available experimental techniques, providing detectable experimental signatures.

8:24AM G5.00003 Quantum degenerate Bose-Fermi mixture of chemically different atomic species with widely tunable interactions†, JEE WOO PARK, CHENG-HSUN WU, IBON SANTIAGO, Massachusetts Institute of Technology, TOBIAS TIECKE, Harvard University, SEBASTIAN WILL, PEYMAN AHMADI, MARTIN ZWIERLEIN, Massachusetts Institute of Technology — We have created a quantum degenerate Bose-Fermi mixture of $^{40}$Na and $^{40}$K with widely tunable interactions via broad interspecies Feshbach resonances. Over thirty Feshbach resonances between $^{40}$Na and $^{40}$K were identified, including $p$-wave multiplet resonances. The large and negative triplet background scattering length between $^{23}$Na and $^{40}$K causes a sharp enhancement of the fermion density in the presence of a Bose condensate. As explained via the asymptotic bound-state model (ABM), this strong background scattering leads to wide Feshbach resonances observed at low magnetic fields. Our work opens up the prospect to create chemically stable, fermionic ground state molecules of $^{23}$Na-$^{40}$K where strong, long-range dipolar interactions would set the dominant energy scale.

†Work was supported by the NSF, AFOSR-MURI and -PECASE, ARO-MURI, ONR YIP, DARPA YFA, a grant from the Army Research Office with funding from the DARPA OLE program and the David and Lucille Packard Foundation.

8:36AM G5.00004 Probing Quantum Magnetism with Polar Molecules via Interaction Induced Dephasing, SALVATORE R. MANIANA, KADEN R.A. HAZZARD, ANA MARIA REY, JILA / University of Colorado at Boulder — We show that strongly coupled many body states of quantum magnetic models can be dynamically generated even under current experimental conditions [1] at low filling factors and at temperatures above quantum degeneracy. This opens the way to verify a recent theoretical prediction [2] that the molecules' rotational states can be used to directly emulate quantum spins with strong ($> 1$kHz) "spin-spin" interactions. We do this by considering the dynamics of fully polarized initial states which are easily realized in current experiments. Our analytic and DMRG calculations show that the dynamic experiments can quantitatively verify and characterize the spin model (XXZ) description of the system. As an outlook we propose how to experimentally generate interesting entangled states with polar molecules.


8:48AM G5.00005 Controlling molecular scattering in optical lattices and fields†, GOULVEN QUÉMÉNER, JOHN BOHN, JILA, University of Colorado, Boulder — Experimental physicists accomplished striking progress in preparing ultracold polar molecules in a precise quantum state [1]. Soon enough, one can envision "ideal" experiments of molecular physics where all quantum states of molecules can be addressed and detected. In addition, ultracold polar molecules benefit from a vast tool set of controls. Molecular chemical reactions can be enhanced by electric fields [2] or can be suppressed by optical lattices [3]. If the molecules have a magnetic dipole moment, they can also be controlled by magnetic fields. Starting from these ideas, we want to investigate what would be a scattering event between two molecules in an optical lattice, and in the presence of an electric and magnetic field. We will choose, as a probe example, the OH molecule which has either an electric and magnetic dipole moment. We will compare the effect of these additional external controls on the differential cross section and ask if we can trace back some information on the inter-molecular potential.


†We acknowledge funds from the Air Force Office of Scientific Research.

9:00AM G5.00006 The Molecular Hubbard Hamiltonian: field regimes and molecular species, M.L. WALL, E. BEKAROGLU, L.D. CARR, Colorado School of Mines — The Molecular Hubbard Hamiltonian (MHH) is a lattice many-body Hamiltonian describing the low energy physics of $\Sigma$ heteronuclear alkali dimers loaded into an optical lattice. We present an overview of the derivation of this Hamiltonian, focusing in particular on how its parameters may be tuned experimentally. We also present a thorough exposition of the scales of the problem down to 1Hz, which allows for truncation of long-ranged terms in the MHH to a consistent level of approximation. The most experimentally relevant species KRb, LiCs, and RbCs access very different regimes of the MHH, and so will have different many-body features. We exemplify this point with Matrix Product State (MPS) simulations of the MHH for these species in near-term experimental configurations.
9:12AM G5.00007 Tunable Holstein model with cold polar molecules, FELIPE HERRERA, ROMAN V. KREMS, University of British Columbia — We show that ultracold polar molecules trapped on an optical lattice can be used for quantum simulation of the Holstein polaron model. Rotational excitation of molecules on the lattice produces excitons that are coupled to lattice phonons due to long-range dipole-dipole interactions. We show that the properties of the excitons and the phonons as well as the exciton-phonon couplings can be controlled by applying a dc electric field and by varying the intensity of the trapping laser field. We discuss the application of polar molecules on an optical lattice for quantum simulation of non-Markovian open quantum systems. We also explore the possibility of realizing a transition from the strongly coupled Holstein polaron limit to the polaron regime described by the Su-Schrieffer-Heeger model. Reference: F. Herrera and R. V. Krem, Phys. Rev. A 84, 051401(R) (2011).

9:24AM G5.00008 Correlation functions of dipolar gases at zero and non-zero temperatures, CHRISTOPHER TICKNOR, ANDREW SYKES, Los Alamos National Laboratory — We study phase and density fluctuations in a quasi-2D dipolar gas. We employ the Hartee-Fock-Bogoliubov (HFB) method to study finite temperature phase coherence. We use this method to study the Berezinskii-Kosterlitz-Thouless (BKT) transition. We contrast the results for dipolar-interactions to contact-interactions and compare our predictions against recent experiments. Additionally, we present analytic expressions for the correlation functions at zero temperature. We observe the formation of a roton in the excitation spectrum as one varies the ratio between 2D-confinement-width and correlation (healing) length. We study the effect of this roton on the few-body correlation functions in the system.

9:36AM G5.00009 Ultracold collisions between optically trapped sodium and rubidium atoms, DAJUN WANG, TING-FAI LAM, XIAOKE LI, FUDONG WANG, DEZHI XIONG, Department of Physics, the Chinese University of Hong Kong, Shatin, Hong Kong — NaRb molecule is a nice candidate for studying quantum gases with dipolar interactions because of its large electric dipole moment (3.3 Debye) and stability against exchange chemical reactions. We have constructed an all optical setup for producing ultracold Na and Rb atoms to obtain collisional and molecular spectroscopy information necessary for producing ground-state NaRb molecules. After loading an optical dipole trap directly from the two-species magneto-optical traps, evaporative cooling is applied by lowering the dipole trap potential. Heteronuclear photoassociation is then performed in the optical dipole trap near the Na (3S) + Rb (5P) asymptote. Progress toward the observation of Feshbach resonances between Na and Rb atoms will also be discussed. We are supported by Hong Kong RGC CUHK 403111.

9:48AM G5.00010 Controlling Interactions of Ultracold Er Atoms with Feshbach Resonances1, SVETLANA KOTOCHIGOVA, ALEXANDER PETROV, Temple University — Here we pursue ideas for using anisotropic dipole-dipole and dispersion interactions to control collisional properties of ultracold magnetic Erbium (Er) atoms by using Feshbach resonances (FR). This kind of control will allow for converting a weakly interaction gas of atoms to a strongly interacting gas that can exhibit novel collective many-body states. Alternatively, interactions can be turn off all together to create an ideal gas, for which thermodynamic properties are known analytically. Feshbach resonances can also be used to create a BEC and associate atoms into highly magnetic molecules. For fermionic magnetic atoms the BCS-BEC phase transition and universal behavior of infinitely-strong interacting atoms can be studied. Finally, Efimov physics for the complex non-alkali atoms can be explored. The most interesting collision experiment occurs when magnetic Er atoms are prepared in the energetically-lowest Zeeman state \( \ell = 0 \) and projection \( m_\ell = -6 \) at nanokelvin temperatures, as Feshbach resonances can be observed. Resonances in magnetic atoms must rely on anisotropic couplings to bound state with non-zero partial wave \( \ell \). This is in contrast to collisions of alkali-metal atoms. Anisotropic interactions are much weaker there and, in addition, the hyperfine interaction between the electron and nuclear spin gives sufficient complexity so that most FR are due to s-wave bound states.

1We acknowledge support from grants of the Air Force Office of Scientific Research and NSF PHY-1005453.

Wednesday, June 6, 2012 8:00AM - 10:00AM — Session G6 Precision Measurements and Tests of Basic Physics

Garden 4 - Chair: Subhadeep Gupta, University of Washington

8:00AM G6.00001 Atom Interferometry with Bose-Einstein condensates to measure \( \alpha \), ALAN JAMISON, BEN PLOTKIN-SWING, ANDERS HANSEN, ALEXANDER KRHAMOV, WILL DOWD, J. NATHAN KUTZ, SUBHADEEP GUPTA, University of Washington. The most precise measurement of the fine structure constant, \( \alpha \), comes from the electron \( g - 2 \) measurement. This result relies on high orders of perturbation theory in QED. A complementary measurement of \( \alpha \) with less dependence on theory would allow for extremely stringent tests of QED. Atomic recoil measurements, which measure \( h/m \) for a given atomic species, are a promising direction for such a measurement. We will report on our progress toward a Bose-Einstein condensate (BEC) interferometer to measure the atomic recoil of ytterbium (Yb) with high precision. Use of a BEC allows for long interrogation times and a robust signal. Using Yb eliminates magnetic fields as a potentially damaging systematic while allowing comparison of results for different isotopes. We have established key components of the interferometer with a \( ^{174}\text{Yb} \) BEC: diffraction with short laser pulses for momentum-state beam-splitting and with long pulses as mirrors. We are working on acceleration pulses to achieve large momenta in the different interferometer arms, necessary for a sub-ppb measurement of \( \alpha \).

8:24AM G6.00002 Precision Atomic Masses of Calcium, Strontium and Ytterbium1, EDMUND MYERS, RAMAN RANA, Florida State University, MARTIN HOECKER, MPI-K, Heidelberg — Currently the second most precise value for the fine structure constant is derived from “photon-recoil” measurements of \( h/M(\text{Rb}) \) combined with the Rydberg constant, atomic transition frequencies, and the atomic masses of the electron and rubidium. An improved photon-recoil value for \( \alpha \) will enable the combination of theory and experiment for the g-factor of the electron, which produces the most precise value for \( \alpha \). To provide an improved test of QED. Besides the alkalis, isotopes of the alkaline-earths and ytterbium can make promising candidates for precise photon-recoil measurements of \( h/M(\text{atom}) \). In addition, the mass of 40Ca is required for obtaining the g-factor of hydrogen-like calcium from measurements of electron spin-flip and cyclotron frequencies of Ca19+, which would provide a test of bound-state QED theory. For these and other applications, we have now measured cyclotron frequency ratios of pairs of ions in a cryogenic Penning trap that should yield the atomic masses of 40Ca, 86,87,88Sr, and 170,171,172,173,174,176Yb to a precision of ~0.2 ppb.

1Work supported in part by NSF PHY-0968889.

8:24AM G6.00003 Polarizability measurements of alkali atoms using an atom interferometer, IVAN HROMADA, WILLIAM HOLMGREN, RAISA TRUBKO, ALEXANDER CROMHOUT, University of Arizona — We present our latest static polarizability measurements of the alkali atoms Li through Cs. Our measurements rely on a gradient electric field region in our atom interferometer. We have demonstrated 0.1% precision in polarizability and 0.05% precision in atom beam velocity measurements. Because we use the same apparatus to measure the polarizabilities of different atomic species, we are able to report polarizability ratios (e.g., \( \alpha_{Cs}/\alpha_{Li} \)) with similar precision. We discuss the systematic errors that limit the precision of our absolute and ratio measurements. These measurements provide benchmark tests of complex atomic structure calculations needed for atomic clocks and parity non-conservation experiments.
8:36 AM G6.00004 Model independent analysis of proton structure for hydrogenic bound states, GIL PAZ, Wayne State University — The charge radius of the proton is a basic non-perturbative parameter. Recently, it was extracted for the first time from the Lamb shift in muonic hydrogen. For a long time it was anticipated that such a measurement would reduce the error by an order of magnitude compared to measurements from electron-positron scattering and regular hydrogen spectroscopy. While this goal was achieved, the value of the proton’s charge radius that was obtained was, very surprisingly, five standard deviations away from the world average. The extraction of the charge radius from the Lamb shift in muonic hydrogen depends on a theoretical input. Together with Richard J. Hill, we are studying the hadronic uncertainty in the theoretical prediction using the tool of effective field theory, namely NRQED. In the talk I will describe the results of this study.

8:48 AM G6.00005 Nuclear and QED corrections to the bound-electron g factor, JACEK ZATORSKI, NATALIA S. ORESHKINA, CHRISTOPH H. KEITEL, ZOLTÁN HARMAN, Max Planck Institute for Nuclear Physics, Saupfercheckweg 1, 69117 Heidelberg, Germany — We calculate nuclear shape and quantum electrodynamic corrections to the g factor of a bound electron [1,2]. These theoretical studies are motivated by the current improvement of experimental possibilities: on the one hand, in a recent Penning trap measurement [2], the g factor of $^{28}$Si$^{+13}$ has been determined with an unprecedented $5 \times 10^{-10}$ relative uncertainty. A novel experimental technique will further improve accuracy to the $10^{-11}$ level. On the other hand, experiments with ions as heavy as $^{238}$Pu$^{+11}$ will be performed soon at the HITRAP-FAIR facility. For such heavy ions, nuclear effects play an important role. The leading relativistic nuclear deformation correction has been derived analytically and also its influence on one-loop quantum electrodynamic terms has been evaluated. We present results for medium- and high-Z hydrogenic ions which become significant already for mid-Z ions, and for very heavy elements it even reaches the $10^{-6}$ level, as we show in [1].


9:00 AM G6.00006 Measuring the atomic recoil frequency with a grating-echo atom interferometer, BRYNLE BARRETT, ADAM CAREW, A. KUMARAKRISHNAN, Department of Physics and Astronomy, York University — We discuss progress toward a precise measurement of the atomic recoil frequency using a grating-echo atom interferometer. Large laser-cooled samples of $^{87}$Rb with temperatures as low as 2.4 μK have been achieved in a new experimental apparatus with a well-controlled magnetic environment. We have realized interferometer signal lifetimes approaching the transit time limit in this system (~ 270 ms), which is comparable to the timescale of Raman interferometers. The measurement technique involves exciting the sample with three chirped standing wave pulses, and mapping out the contrast of an atomic density grating as a function of the third pulse time. The signal exhibits narrow fringes that are separated by measurement timescales of ~ 50 ms. This interferometer can also be used for sensitive measurements of magnetic field gradients and gravitational acceleration [B. Barrett et al., Phys. Rev. A 84, 063623 (2011)].

9:12 AM G6.00007 Towards optical pumping of ytterbium nuclei embedded in a solid neon matrix, CHEN-YU XU, Argonne National Laboratory and University of Chicago, JAIDEEP SINGH, KEVIN BAILEY, Argonne National Laboratory, ZHENG-TIAN LU, Argonne National Laboratory and University of Chicago, PETER MUELLER, THOMAS O’CONNOR, Argonne National Laboratory — We have studied the optical excitation and decay dynamics of neutral ytterbium atoms embedded in a cryogenic solid neon matrix. Matrix isolated atoms qualitatively retain the energy level structure of atoms in the gas phase. The transitions are typically blue shifted and significantly broadened to a few hundred cm$^{-1}$, independent of temperature from 2.6 K to 4.2 K. The transition width is found to be homogeneous but not lifetime broadened. We will report our results on spectroscopy, lifetimes, and our attempt to polarize nuclear spins by optical pumping. Applications of such a technique include studies of rare isotopes and tests of fundamental symmetries. This work is supported by DOE, Office of Nuclear Physics, under contract DEAC02-06CH11357.

9:24 AM G6.00008 Investigation for the Macroscopic Quantum Electrodynamics to describe light in dielectric material, MOOCHE B. KIM, TAE-WOO LEE, GEORGIOS VERONIS, HWANG LEE, JONATHAN P. DOWLING, Hearne Institute for Theoretical Physics, Louisiana State University, Baton Rouge, Louisiana 70803, USA — Though the behavior of photons in medium can be easily formulated in usual microscopic Quantum Electrodynamics, the presence of matter makes this dicult to describe due to nontrivial degrees of freedom of matter. Alternative approach is to begin with macroscopic Maxwell’s equation including a dielectric material. It may be useful to predict the behavior of the system. Until now, a few theories for macroscopic QED was suggested without a confirmation. To discern the proper description for the system, we investigate and suggest experiments for a simple optical interferometer, such as the Hong-Ou-Mandel and Mach-Zehnder interferometers, which may be made in integrated dielectric materials.

9:36 AM G6.00009 Enhanced Sensitivity in a Superluminal Single Mode DPAL Cavity at Room Temperature, TONY ABI-SALLOUM, Department of Physics and Astronomy, Widener University, Chester, PA 19013, USA, JOSHUA YABLON, SHIH TSENG, Department of Physics and Astronomy, Northwestern University, Evanston, IL 60208, USA, SELIM SHAHRRIAR, Department of Physics and Astronomy & Department of EECS, Northwestern University, Evanston, IL 60208 — The note beat between two counter-propagating beams in a cavity is used to measure the effective change of the length of the cavity or interferometer for applications such as optical gyroscopes, vibrometers, and gravitational wave detectors. We show in this talk how a superluminal single mode laser cavity can enhance the measured note beat dramatically. We consider the inhomogeneous broadening case and study the dependence of the enhancement factor on few key parameters. We also show how Diode Pump Alkali Lasers (DPAL) are excellent candidates for such devices. Using a Rubidium based DPAL, we study the characteristics of these lasers and their effect on the proposed enhanced sensitivity.

9:48 AM G6.00010 Precise measurements of microwave transitions in CH with high sensitivity to variation of fundamental constants, STEFAN TRUPPE, RICHARD HENDRICKS, SEAN TOKUNAGA, EDWARD HINDS, MICHAEL TARBUJT, Centre for Cold Matter, Blackett Laboratory, Imperial College London, London, SW72BW, UK — Recent calculations [1] show that the Lambda-doublet transitions of certain diatomic molecules are highly sensitive to possible variations of the electron-to-proton mass ratio and the fine structure constant. The lowest-lying Lambda-doublets of the CH molecule are particularly sensitive and can be observed in astrophysical objects at high red-shift, offering a precise test of variations in these fundamental constants over billions of years, without needing reference lines from other species. To improve the current laboratory measurements of these microwave transitions, we have developed a cold beam of CH radicals and have measured the transition frequencies to high precision using the Ramsey method of separated oscillatory fields.


Wednesday, June 6, 2012 8:00AM - 10:00AM — Session G7 Invited Session: Cavity Optomechanics — Terrain - Chair: Pierre Meystre, University of Arizona
8:00AM G7.00001 Quantum aspects of cavity optomechanics with atomic ensembles and ensemble arrays, DAN STAMPER-KURN, University of California, Berkeley — While the motion of a many-atom ensemble of atoms interacting strongly with a single mode of an optical resonator can be devilishly complicated, under favorable conditions, the cavity can be made to interact with and to sense just one, or just a few, normal modes of the gaseous system. This leads to an atoms-based realization of cavity optomechanics, directly analogous to experiments in which one seeks to observe the motion of suspended mirrors, cantilevers, and membranes at the quantum limits of precision. I will discuss our progress toward demonstrating and understanding the distinctively quantum mechanical aspects of both the “opto” and “mechanical” portions of cavity optomechanical systems. Specifically, I will report on the observation of the so-called permanent transparency of light by a mechanical oscillator, and on strong quantum sideband asymmetry that demonstrates the quantization of collective atomic motion and quantifies the energy flux into the mechanical system due to quantum measurement backaction. I will conclude by describing our approach to realizing strong cavity coupling to a multi-mode mechanical system, specifically to an array of distinguishable mechanical oscillators.

The work reported in this talk was performed in collaboration with members of my research group, including Thierry Botter, Nathaniel Brahms, Daniel Brooks, Thomas Purdy and Sydney Schreppel, and was supported by the AFOSR and NSF.

8:30AM G7.00002 Optomechanical crystals, OSKAR PAINTER, California Institute of Technology — In the last several years, rapid advances have been made in the field of cavity optomechanics, in which the usually feeble radiation pressure force of light is used to manipulate, and precisely monitor, mechanical motion. Amongst the many new geometries studied, coupled phononic and photonic crystal structures (dubbed optomechanical crystals) provide a means for creating integrated, chip-scale, optomechanical systems. Applications of these new nano-opto-mechanical systems include all-optically tunable photonics, optically powered RF and microwave oscillators, and precision force/acceleration and mass sensing. Additionally there is the potential for these systems to be used in hybrid quantum networks, enabling storage or transfer of quantum information between disparate quantum systems. A prerequisite for such quantum applications is the removal of thermal excitations from the low-frequency mechanical oscillator. In this talk I will describe our recent efforts to optically cool and measure the quantum mechanical ground-state of a GHz oscillator (see figure below), and to demonstrate efficient translation between light and sound quanta.

9:00AM G7.00003 Sideband Cooling Micromechanical Motion to the Quantum Ground State, JOHN TEUFEL, NIST Boulder — Accessing the full quantum nature of a macroscopic mechanical oscillator first requires elimination of its classical, thermal motion. The flourishing field of cavity optomechanics provides a nearly ideal architecture for both preparation and detection of mechanical motion at the quantum level. We realize a microwave cavity optomechanical system by coupling the motion of an aluminum membrane to the resonance frequency of a superconducting circuit [1]. By exciting the microwave circuit below its resonance frequency, we damp and cool the membrane motion with radiation pressure forces, analogous to laser cooling. Microwave excitation serves not only to cool, but also to monitor the displacement of the membrane. A nearly shot-noise limited, Josephson parametric amplifier is used to detect the mechanical sidebands of this microwave excitation and quantify the thermal motion as it is cooled with radiation pressure forces to its quantum ground state [2].


9:30AM G7.00004 Cavity Optomechanics: Coherent Coupling of Light and Mechanical Oscillators, TOBIAS J. KIPPERNBERG, EPFL — The mutual coupling of optical and mechanical degrees of freedom via radiation pressure has been a subject of interest in the context of quantum limited displacements measurements for Gravity Wave Detection for many decades, however light forces have remained experimentally unexplored in such systems. Recent advances in nano- and micro-mechanical oscillators have for the first time allowed the observation of radiation pressure phenomena in an experimental setting and constitute the expanding research field of cavity optomechanics [1]. These advances have allowed achieving to enter the quantum regime of mechanical systems, which are now becoming a third quantum technology after atoms, ions and molecules in a first, electronic circuits in a second wave. In this talk I will review these advances. Using on-chip micro-cavities that combine both optical and mechanical degrees of freedom in one and the same device [2], radiation pressure back-action of photons is shown to lead to effective cooling [3-6] of the mechanical oscillator mode using dynamical backaction, which has been predicted by Braginsky as early as 1969 [4]. This back-action cooling exhibits many close analogies to atomic laser cooling. With this novel technique the quantum mechanical ground state of a micromechanical oscillator has been prepared with high probability using both microwave and optical fields. In our research this is reached using cryogenic precooing to ca. 800 mK in conjunction with laser cooling, allowing cooling of micromechanical oscillator to only motional 1.7 quanta, implying that the mechanical oscillator spends about 40% of its time in the quantum ground state. Moreover it is possible in this regime to observe quantum coherent coupling in which the mechanical and optical mode hybridize and the coupling rate exceeds the mechanical and optical decoherence rate [7]. This accomplishment enables a range of quantum optical experiments, including state transfer from light to mechanics using the phenomenon of optomechanically induced transparency [8]. From a broader perspective the described experiments that exploit optomechanical coupling are motivated both by the effort to realize quantum measurement schemes on mechanical systems in an experimental setting as well as to explore the behavior of nanomechanical systems at low temperatures.

10:30AM H1.00001 Universality of the Three-Body Parameter for Efimov States in Ultracold Cesium\textsuperscript{1}, RUUDOLPH GRIMM\textsuperscript{2}, Institute of Experimental Physics, Univ. Innsbruck, and IQOQI, Austrian Academy of Sciences, Innsbruck, Austria — We review recent progress in our understanding of universal few-body physics, considering the particular example of ultracold cesium gases with widely tunable s-wave interactions. We discuss the question of the so-called three-body parameter, which together with Efimov’s famous scaling law fixes the values of the scattering length where three-body recombination resonances occur. A collection of experimental results on Cs and other species and recent theoretical results show a new type of universality for atomic systems, which connects the three-body parameter to the length scale introduced by the van der Waals interaction. Further progress has also been made regarding the generalization of Efimov’s scenario to universal few-body cluster states. We report on the first observation of a five-body recombination resonance, which strongly supports the theoretical predictions on the existence of a universal series of N-body states. Moreover, we present new experimental results on modifications of Efimov physics in the dimensional crossover when the 3D confinement is changed into a 2D one.

\textsuperscript{1}Supported by the Austrian Science Fund FWF within project P23106.

\textsuperscript{2}Work done in collaboration with P. Julienne (JQI), J. Hutson (Univ. Durham, UK), J. von Stecher and C. Greene (JILA, Boulder) and the Innsbruck experimental team M. Berninger, Bo Huang, A. Zenesini, H.-C. Nägerl, and F. Ferlaino.

11:00AM H1.00002 Few-body physics for bosonic and fermionic dipoles\textsuperscript{1}, YIJUN WANG, JILA and Physics, University of Colorado at Boulder — This invited talk, coauthored by Jose D’Incaio and Chris Greene, will review our theoretical evidence that predicts an Efimov effect for three interacting bosonic polar molecules. Interestingly, the hyperspherical coordinate treatment shows a universal barrier which implies that the three-body parameter is rather accurately known in terms of the dipole length. It was not a foregone conclusion that three bosonic dipoles would exhibit Efimov physics, given that the original derivation and also subsequent work was for systems with short-range interactions only, and moreover, for systems having conserved angular momentum. Despite the fact that neither of these properties holds for three bosonic dipoles oriented in an external electric field, Efimov physics emerges naturally. For three fermionic dipoles in the same spin state, on the other hand, there is no Efimov effect, but there is a single universal bound (or quasi-bound) state predicted to occur. Conditions under which these novel 3-dipole states could be observed experimentally will be discussed at the meeting.

\textsuperscript{1}Supported by AFOSR-MURI and NSF

11:30AM H1.00003 Crossover between universal trimers and Efimov trimers, SHIMPEI ENDO, University of Tokyo, PASCAL NAIDON, RIKEN, MASAHIITOUEDA, University of Tokyo — For a system of two identical fermions and one distinguishable particle interacting via a short-range potential with a large s-wave scattering length, Efimov trimers \cite{1} and universal trimers \cite{2} exist in different regimes of mass ratio. These trimers have different scaling symmetry: discrete and continuous scaling symmetry. We point out the existence of a third kind of trimers, “crossover trimers,” that continuously connect the two regimes as the mass ratio and the scattering length are varied.

\begin{itemize}
\end{itemize}

12:00PM H1.00004 Efimov physics in a mixture of $^{40}$K and $^{87}$Rb\textsuperscript{1}, TYLER CUMBY, RUTH SHEWMON, MING-GUANG HU, DEBORAH JIN, JILA, National Institute of Standards and Technology and University of Colorado; Physics Department, University of Colorado, Boulder, Colorado 80309 — Three-body Efimov resonances have now been detected in a number of ultracold atom species using measurements of three-body recombination rates. Moreover, recent observations suggest that the locations of these resonances has some universality, in that they can be predicted using the two-body van der Waals length \cite{1}. To compare with a recent prediction for the $^{40}$K + $^{87}$Rb system \cite{2} and with a previous experimental result for $^{41}$K + $^{87}$Rb \cite{3}, we measure three-body recombination and molecule loss rates in an ultracold trapped gas of $^{40}$K and $^{87}$Rb atoms near an interspecies Feshbach resonance.

\begin{itemize}
  \item [1] PRL 107, 120401 (2011)
  \item [2] arXiv:1111.1484v1
  \item [3] PRL 103, 043201 (2009)
\end{itemize}

\textsuperscript{1}Funding: NSF and ASEE

12:30PM H1.00005 Origin of the Three-body Parameter Universality in Efimov Physics\textsuperscript{1}, JIA WANG, J.P. D’INCAO, Department of Physics and JILA, University of Colorado, Boulder, B.D. ESRY, Department of Physics, Kansas State University, CHRIS H. GREENE, Department of Physics and JILA, University of Colorado, Boulder — One of the most fundamental theoretical assumptions concerning Efimov physics is that the three-body parameter depends on the precise details of the short-range two- and three-body interactions, i.e., it is not a universal parameter. Surprisingly, and contrary to this assumption, recent experiments exploring Efimov physics in ultracold quantum gases have found that the three-body parameter is universal. The present study investigates the origin of the universality of the three-body parameter in identical bosonic systems using the adiabatic hyperspherical representation. Our study shows that the universality of the three-body parameter emerges because a universal effective barrier in the important three-body potential prevents the three particles from simultaneously getting close to each other. Our results also set limits on this universality, showing it to be more likely to occur for neutral atoms and less likely to extend to light nuclei.

\textsuperscript{1}This work was supported by the National Science Foundation and AFOSR-MURI.

12:30PM H1.00006 Universal three-body parameters in heteronuclear atomic systems\textsuperscript{1}, YIJUN WANG, JIA WANG, JOSE D’INCAO, CHRIS GREENE, Department of Physics and JILA, University of Colorado — Following the recent experimental and theoretical identifications of a universal three-body parameter in ultracold bosonic gases, we have calculated three-body parameters in heteronuclear three-atomsystems near Feshbach resonances between distinguishable atoms. It is found that the three-body parameters, or the ground Efimov state energies, are universally determined by a combination of the long-range van der Waals interactions and the homonuclear scattering length. The positions of all the Efimov features in three-atom scattering processes in these heteronuclear systems can therefore be uniquely known. We show three-body parameters for some combinations of commonly-used alkali atoms in ultracold experiments with a wide range of homonuclear scattering lengths, and give an intuitive picture for understanding the universality in the Born-Oppenheimer limit where one of the atoms is much lighter than the others. Such knowledge of three-body parameters can be conveniently used to precisely calibrate the positions of the magnetic Feshbach resonances in ultracold experiments.

\textsuperscript{1}Supported by the National Science Foundation and AFOSR-MURI
12:18PM H1.00007 A new class of three-body states beyond the Efimov effect\textsuperscript{1}, NICOLAIS L. GUEVARA, BRETT D. ESRY, Department of Physics. Kansas State University — Recently, we have identified a new type of three-body bound state for three identical bosons interacting via attractive two-body $1/r^2$ potentials \cite{1}. These three-body states are bound even when the two-body subsystem does not support a dimer state. In fact, there are an infinity of such states. We will present an extension of this work to the system with two identical bosons ($B$) and one distinguishable particle ($X$). We have investigated the spectrum of this $BBX$ system assuming only that the $B + X$ interaction is an attractive $1/r^2$ potential. We have again found an infinite number of three-body bound states even though the two-body potential does not support a bound state. This effect is shown to exist at large \textit{a} mass ratios ($M_B/M_X$) and depends on the strength of the two-body interaction. The most favorable case is the molecular-type system, i.e., $M_B/M_X \gg 1$.

\textsuperscript{1}Supported by the National Science Foundation

\begin{center}
\textbf{Wednesday, June 6, 2012 10:30AM - 12:30PM – Session H2 Disorder in Quantum Gases Grand Ballroom GF - Chair: Brian DeMarco, University of Illinois Urbana-Champaign}
\end{center}

\textbf{10:30AM H2.00001 Studies of disordered quasi-2D Bose gasses\textsuperscript{1}, MATTHEW REED, ZACK SMITH, STEVEN ROLSTON, JQI/UMD — We present trapped quasi-2D Bose gasses in an optical speckle disorder. The disorder’s correlation length, at 1 micrometer, is on the order of the atomic de-Broglie wavelength ($\lambda$ between 350 and 500 nm) and the healing length (250 to 1000 nm) of our trapped gasses. This is a parameter regime whose properties have been resistant to analytical and numerical study, and in the case of disorder with a nontrivial autocorrelation function, the ground state is unknown. Using one plane as a phase reference for a second, we analyze the coherence properties of the trapped gas by studying both the average phase in the imaging direction and the visibility of the fringes. We correlate a reduction in phase coherence with increased variance of the disorder, and correlate this with both phonon and vortex statistics in both adiabatically prepared samples and in quenched gasses.}

\textsuperscript{1}JQI

\textbf{10:42AM H2.00002 Disordered Hubbard model with ultracold atoms\textsuperscript{1}, STANIMIR KONDOV, WILLIAM MCGHEE, JOSHUA ZIRBEL, BRIAN DEMARCO, University of Illinois at Urbana-Champaign — We report progress in studying the effects of disorder on the phase diagram of the Hubbard model. The resulting disordered Hubbard model (DHM) is the subject of intense research in condensed matter physics due to its applicability to strongly correlated electronic systems. We realize the DHM using ultracold $^{40}$K atoms in an optical lattice superimposed with a speckle light field. The aim of our study is to explore the variety of metallic and insulating phases which arise in the interplay between kinetic energy, interactions and disorder.}

\textsuperscript{1}We acknowledge funding from the ONR, NSF, and DARPA OLE program.

\textbf{10:54AM H2.00003 Phase Diagram of Commensurate Two-Dimensional Disordered Bose Hubbard Model, SEBNEM GUNES SOYLER, MIKHAIL KISELEV, The Abdus Salam International Centre for Theoretical Physics, NIKOLAY PROKOF’EV, BORIS SVISTUNOV, Department of Physics, University of Massachusetts Amherst — We do quantum Monte-Carlo simulations to calculate the full ground state phase diagram of the two dimensional disordered Bose-Hubbard model at unity filling factor. We observe superfluid regions persisting up to large values of disorder and interaction strength. In the vicinity of the superfluid-insulator transition of the pure system, the system shows almost unmeasurable response to weak disorder.}

\textbf{11:06AM H2.00004 Polaronons in a strongly interacting Bose-Fermi mixture\textsuperscript{1}, CHENG-HSUN WU, IBON SANTIAGO, JEE WOO PARK, PEYMAN AHMADI, SEBASTIAN WILL, MARTIN ZWIERLEIN, Massachusetts Institute of Technology — The fate of an impurity interacting with its environment is a fundamental problem in condensed matter physics. The famous example is that of an electron moving in the crystal background of ions, dressing itself with lattice distortions, phonons. In ultracold atomic systems, impurities interacting with a Fermi sea have been studied, leading to the observation of Fermi polaronons. Here we study the interaction of an impurity immersed in a Bose-Einstein condensate of $^{23}$Na. We perform radio-frequency spectroscopy on the impurity atom and the bath, which is expected to probe the spectral features characteristic for polaronic dressing: A delta-like peak in addition to a broad pedestal coming from the interactions between the impurity and the phonons in the condensate. A mixture of $^{23}$Na and $^{40}$K with its widely tunable interactions promises to be an ideal system to study the evolution from Bose polaronons to Fermi polaronons as the imbalance between $^{23}$Na and $^{40}$K is varied.}

\textsuperscript{1}Work was supported by the NSF, AFOSR-MURI and -PECASE, ARO-MURI, ONR YIP, DARPA YFA, a grant from the Army Research Office with funding from the DARPA OLE program and the David and Lucille Packard Foundation.

\textbf{11:18AM H2.00005 Dynamics of Bose-Einstein condensates and wave chaos, IVA BREZINOVA, Vienna University of Technology, LEE A. COLLINS, Los Alamos National Laboratory, BARRY I. SCHNEIDER, National Science Foundation, AXEL U.J. LODE, ALEXEJ I. STRELTSOV, Heidelberg University, OFIR E. ALON, University of Haifa at Oranim, LORENZ S. CEDERBAUM, Heidelberg University, JOACHIM BURGDORFER, Vienna University of Technology — We study theoretically the expansion of BECs in a one-dimensional trap in the presence of external periodic, aperiodic, and disordered potentials. Disordered potentials are of special interest in the connection of Anderson localization. We investigate the dynamics of BECs within both the Gross-Pitaevskii equation (GPE) as well as the multiconfigurational time-dependent Hartree model for bosons (MCTDHB) method. The GPE is strictly valid only for the condensate. We find that for certain potentials the solutions of the GPE exhibit wave chaos as measured by the exponential divergence of nearby wave functions in Hilbert space. We provide numerical evidence for the connection between wave chaos within the GPE and depletion of the condensate. We show that the ability of the GPE to predict the density on length scales of the potential variations is limited by the appearance of wave chaos. Surprisingly, despite a strong depletion of the condensate, coarse-grained observables averaged over larger scales, e.g., the width of the atom cloud, are well reproduced within the GPE. Accordingly, experimental results for these observables may agree with the predictions of the GPE although the system is strongly excited. The depletion can be detected experimentally through decay of coherence.
11:30AM H2.00006 Probing mean-field screening in a tilted incommensurate lattice, JEREMY REEVES, MATTHIAS VOGT, BRYCE GADWAY, DANIEL PERTOT, DOMINIK SCHNEBLE, Department of Physics and Astronomy, Stony Brook University — There has been recent interest in the competing roles of disorder and interactions on the dynamics of ultracold gases in optical lattices. Here, we investigate a weakly interacting Bose-Einstein condensate in a tilted incommensurate lattice potential. It is well known that both collisional interactions and disorder individually cause damping of Bloch oscillations. We explore the interplay between the two damping effects and observe a reduction in the disorder-induced damping rate due to the presence of interactions, consistent with screening of disorder.

1Currently at Dept. of Physics and Astronomy, Univ. of Würzburg
2Currently at Cavendish Laboratory, Univ. of Cambridge

11:42AM H2.00007 3D Anderson Localization in Variable-Scale Speckle Potentials, WILLIAM MCEHEE, STANIMIR KONDOV, JOSHUA ZIRBEL, BRIAN DEMARCO, University of Illinois at Urbana-Champaign — Anderson localization in three dimensions is controlled by the interplay between a particle’s Boltzmann mean free path and its wavelength. We extend our measurement of 3D Anderson localization in an interaction-free, ultracold Fermi gas by varying the mean free path through changes in the correlation length of the disordered potential. The potential is created using optical speckle, and the correlation length is varied over a factor of five. We determine how the correlation length affects the mobility edge and the length scale of localization.

11:54AM H2.00008 Effect of Disorder on BCS-BEC Crossover in a Two-dimensional Ultracold Fermi Gas, B. TANATAR, Bilkent University, AYAN KHAN, Pusan National University, SAURABH BASU, IIT Guwahati — We study the BCS-BEC crossover in a two-dimensional ultracold gas of fermionic atoms in the presence of a weak white noise-like random disorder, whose effects are incorporated in the mean-field treatment via Gaussian fluctuations. Self-consistent computation of the physical properties such as the gap parameter and the condensate fraction reveal that the weakly coupled superfluid is unaffected by disorder, whereas the molecular BEC phase is found to be significantly renormalized as the pairing interaction is continuously tuned from a weak to a strong coupling regime. The unitary (crossover) regime, that lies intermediate to the BCS and BEC phases, described by a dimensionless parameter $1/k_{\text{pa}}$, where $-1 \leq 1/k_{\text{pa}} \leq 1$ denotes the region of crossover, shows a monotonic increase of the pairing gap across the crossover, whereas the condensate fraction data is distinct with a non-monotonic behavior. The downturn in the latter result occurs at the crossover regime with a gradual depletion on the BEC side. A non-monotonic feature in the condensate fraction data has been noted earlier, in clean systems. Motivated by this result, we discuss the stability of a disordered fermionic superfluid in the crossover regime.

1Supported by TUBITAK (109T267) and TUBA.

12:06PM H2.00009 Matter-wave dynamics in a periodically pulsed disordered potential, BRYCE GADWAY, JEREMY REEVES, LUDWIG KRINNER, DOMINIK SCHNEBLE, Department of Physics and Astronomy, Stony Brook University — We have experimentally studied the dynamical response of weakly-interacting atomic matter waves to a periodically pulsed, disordered optical lattice potential consisting of two overlapping standing-waves of incommensurate spatial periodicity. For periodic driving with a single-lattice potential, we observe behavior consistent with the kicked-rotor model, namely delocalization in momentum space at Talbot resonances as opposed to dynamic localization otherwise. However, adding the second lattice potential can greatly modify these two effects, which rely on constructive and destructive interference, respectively. In particular, we find that disorder leads to an inversion of the behavior in each case. The added incommensurate lattice destroys localization when the driving is off-resonant and suppresses delocalization for a resonant drive.

12:18PM H2.00010 Free-space, multimode spatial self-organization of cold, thermal atoms, BONNIE L. SCHMITTBERGER, JOEL A. GREENBERG, DANIEL J. GAUTHIER, Duke University — The collective behavior of atoms upon interaction with light has been a topic of increasing interest since it was shown to lead to novel phase transitions. In order to induce a spontaneously-emergent lattice structure, cold atoms are typically placed in a cavity, which provides a sufficiently strong light-matter interaction. While many experiments have employed single-mode cavities, the use of multimode cavities would explore a new regime with the potential to study phenomena such as dislocations and topological defects. However, multimode cavities present certain technical challenges, and a strongly-interacting multimode system existing in free space is desirable. We create such a system by trapping cold, thermal atoms in a highly anisotropic MOT. When we shine counterpropagating beams along the long axis of our trap, we observe a superradiant phase transition from a homogeneous array of atoms to one that is spatially organized. We are able to infer information about this spatial self-organization by observing the superradiant light that is emitted in the form of transverse optical patterns. We find that the patterns spontaneously hop between spatial modes during single realizations of the experiment, and we study the effects of quantum fluctuations on the atomic organization.

1We gratefully acknowledge the financial support of the NSF through Grant #PHY-0855399.

Wednesday, June 6, 2012 10:30AM - 12:30PM –
Session H3 Theory and Computation of Atomic and Molecular Interactions
Grand Ballroom E - Chair: Shaohao Chen, Louisiana State University

10:30AM H3.00001 Universal bound states of two atoms near a Feshbach resonance, SHINA TAN, Georgia Institute of Technology — The Efimov effect was traditionally thought to exist for three or more particles only. It will be shown how to make universal bound states of two atoms only, which will exhibit a universal energy spectrum reminiscent of the Efimov effect, by using potentials to constrain the spatial motion of atoms. The two atoms must be tuned near a scattering resonance. Several related types of such two-body states will be described. These diatomic “artificial molecules,” if isolated from each other, will be free from three-body recombination, and can have long lifetimes in principle, in contrast with the Efimov bound states of three atoms.

1National Science Foundation; Alfred P. Sloan Foundation

10:42AM H3.00002 Controlling the group velocity of colliding ultracold atoms and Bose-Einstein condensates using Feshbach resonances, RANCHU MATHEW, EITE TIESINGA, Joint Quantum Institute — Over the last ten years progress has been made in creating atoms lasers, sources of coherent atoms, based on atomic Bose-Einstein condensates in analogy to optical lasers. The analog of nonlinear four-wave mixing has also been experimentally observed when three Bose-Einstein condensates with carefully tuned or phase-matched relative velocities collide. Here, we report on a theoretical proposal to change the group velocity upon collision between two ultracold atom clouds in analogy to slowing of light in dispersive media. We make use of ultracold collisions near a Feshbach resonance, which gives rise to a sharp variation in scattering length with collision energy and thereby changes the group velocity. We also present an initial analysis of the practicality of the proposal.
10:54AM H3.00003 Laser assisted electron-atom scattering in critical geometries \(^{1}\). NATHAN MORRISON, CHRIS H. GREENE, JILA and Department of Physics, University of Colorado at Boulder — We investigate the scattering of electrons off of neutral targets in the presence of a linearly polarized, low frequency laser field. The laser has large enough extent for the wavefunction to be treated in the Floquet expansion. The scattering geometries of interest are small angles where momentum transfer is nearly perpendicular to the field, and the Kroll Watson approximation breaks down. We use the eigenchannel R matrix method to solve the Schrödinger equation, employing Hamiltonians in both the length and the velocity gauges in different regions. The target atom is represented by a model potential including a screened coulomb term near the origin and a longer range induced dipole interaction. The short range reaction matrix in the Kramers-Henneberger (acceleration) representation is found by matching the velocity gauge R matrix to spherical Gordon-Volkov states, and from this the cross section is derived. Experiments have shown emission and absorption cross sections at small angles to be much higher than the approximation predicts, and we hope to gain insight into the cause of this phenomenon.

\(^{1}\)This work was supported by the DOE.

11:06AM H3.00004 Angular momentum changing transitions in proton-Rydberg hydrogen atom collisions \(^{1}\), D. VRINCEANU, Texas Southern University, R. ONOFRIO, Universita di Padova, Italy, H.R. SADEGHPOUR, Institute for Theoretical Atomic, Molecular and Optical Physics — Collisions between electrically charged particles and neutral atoms are central for understanding the dynamics of neutral gases and plasmas in a variety of physical situations. Specifically, redistribution of angular momentum states within the degenerate shell of highly excited Rydberg states is nonadiabatic and may also play a role in determining a precise ionization fraction in primordial recombination. We provide an accurate, non-perturbative rate coefficient for collisions between protons and H\((n\ell')\) ending in a final state H\((n\ell'\ell')\), represented by the formula

\[
q_{\ell\ell'\to n\ell'}(T) = \frac{3.922 \times 10^{-4}}{\sqrt{\mathcal{K}}} \frac{n^{2}(\ell + \ell') - \ell_{\ell} (\ell + \ell' + 2|\Delta\ell|)}{(\ell + 1/2)|\Delta\ell|^{3}} \text{ cm}^{2}/\text{s},
\]

where \(\ell_{<}\) is the smallest between \(\ell\) and \(\ell'\), and \(\Delta\ell = \ell - \ell'\). The validity of this formula is confirmed by results of classical trajectory Monte Carlo simulations.

11:18AM H3.00005 Analytical Solution for 3D Stationary Schrödinger Equation: application to scattering \(^{1}\), MARZIEH ZARE, YURI ROSTOVTSEV, Center for Non-linear Science, University of North Texas — We have derived and studied the generalized Ricatti equation for the WKB approximation in three dimensions. A new approximated solution of Schrödinger equation is obtained. We show that this solution is more accurate than that of the WKB method. Writing Schrödinger differential equation in an integral form which is suitable for scattering theory, we discuss some applications of the obtained results, in particular, to the scattering problem.

11:30AM H3.00006 Excitation ionization of atoms and diatoms as a test of the all-active-electron MCTDHF method \(^{1}\). DANIEL HAXTON, KEITH LAWLER, C. WILLIAM MCCURDY, Chemical Sciences, Lawrence Berkeley National Lab — We have developed an implementation of the Multiconfiguration Time-Dependent Hartree-Fock (MCTDHF) method [PRA 83, 063416 (2011)]. MCTDHF is an adaptive method for solving the time-dependent Schrödinger equation and we apply it to atoms and diatoms in ultrashort laser pulses. The method is built to describe nonlinear phenomena and incorporates both an all-active-electron representation and the ability to include diatomic nuclear motion without the Born-Oppenheimer approximation. As a diagnostic of the method, we have calculated photoionization cross sections for: valence ionization of Beryllium, and of HF, LiH, and N2 in the fixed nuclei approximation; 1s ionization of Beryllium; and dissociative ionization of H2+ including nuclear motion with full nonadiabatic coupling. We will present results that demonstrate the convergence of the method with respect to the number of time-dependent orbitals and discuss the prospects of the method for describing nonlinear phenomena.

\(^{1}\)Support provided through DOE contract DE-AC02-05CH11231.

11:42AM H3.00007 Chaotic Energy Hopping in Bidirectionally Kicked Rydberg Atoms \(^{1}\), KORANA BURKE, Boston University, KEVIN MITCHELL, University of California at Merced, SHUZHEN YE, BARRY DUNNING, Rice University — A highly excited (n 306) quasi-one-dimensional Rydberg atom exposed to periodic alternating external electric field pulses exhibits chaotic behavior. Time evolution of this system is governed by a geometric structure of phase space called a homoclinic tangle and its turnstile. The turnstile is responsible for organizing chaotic ionization. We present and explain the results from an experiment designed to probe the structure of the phase space turnstile. We create time-independent Rydberg wave packets, subject them to alternating electric field kicks, and measure the ionization fraction. We present the behavior of the ionization fraction as a function of the applied kick strength and show that this behavior is directly connected to the size and shape of the underlying turnstile. For short kicking periods the ionization fraction as a function of the applied kick strength exhibits step-function-like behavior that changes into s-shape behavior for large kicking periods. Next we use the geometric structure of phase space to design a short pulse sequence that quickly and efficiently transfers electronic wave packet from a high ionization fraction as a function of the applied kick strength exhibits step-function-like behavior that changes into s-shape behavior for large kicking periods. We will present results that demonstrate the convergence of the method with respect to the number of time-dependent orbitals and discuss the prospects of the method for describing nonlinear phenomena.

11:54AM H3.00008 ABSTRACT WITHDRAWN —

12:06PM H3.00009 Trends in correlation and confinement impacts on the e-Xe@C\(_{60}\) generalized oscillator strengths \(^{1}\). VALERIY DOLMATOV, University of North Alabama, MIRON AMUSIA, Racah Institute of Physics, Hebrew University, Jerusalem, Israel & A. F. Ioffe Physical-Technical Institute, St. Petersburg, Russia, LARISSA CHERNYSHEVA, A. F. Ioffe Physical-Technical Institute, St. Petersburg, Russia — The response of endohedral Xe@C\(_{60}\) to fast electron impact ionization is theoretically studied by calculating its 4d, 5s and 5p generalized oscillator strengths (GOS). The calculation methodology combines the plane wave Born approximation, single-electron Hartree-Fock approximation, and multi-electron random phase approximation with exchange, all in the presence of the C\(_{60}\) confinement. The confinement is accounted for in the framework of both a spherical \(\delta\)-potential \(^{1}\) and square-well-potential \(^{2}\) models to evaluate the effect of the finite thickness of the C\(_{60}\) cage on said GOS’s. Impressive confinement brought impact on the latter is revealed. Vitality of accounting for electron correlation in calculations of the Xe@C\(_{60}\) 5s and 5p GOS’s is demonstrated. Trends in contributions of multipolar transitions beyond dipole transitions in the calculated GOS’s are unraveled. We challenge experimentalists to conduct corresponding measurements.

\(^{1}\)Supported by the RUI NSF grant No. PHY-0969386, and the Israeli-Russian Grant RFBR-MSTI No. 11-02-92484.
12:18PM H3.00010 Optically controllable photonic structures with zero absorption\(^1\). CHRISTOPHER O’BRIEN, Texas A&M University and University of Kaiserslautern, OLGA KOCHAROVSKAYA, Texas A&M University — We show the possibility to periodically modulate the refractive index in a homogeneous resonant atomic medium in space or/and time while simultaneously maintaining vanishing absorption/gain\(^2\).

Such modulation is based on periodic resonant enhancement of the refractive index via the matching of an effective absorption resonance to an effective gain resonance, controlled by external optical fields, and opens the way to produce coherently controllable photonic structures. We suggest the possible implementation of the proposed scheme in rare-earth doped crystals with excited state absorption. Providing a particular example of how the refractive index can be periodically changed along the optical axis of an Er\(^3+\):YAG crystal to optically produce in a homogenous media, a distributed Bragg reflector with a very high reflectivity.

Wednesday, June 6, 2012 10:30AM - 12:30PM – Session H4 Focus Session: Strong-Field Light-Matter Interactions Garden 1-2 - Chair: Jun Ye, JILA/University of Colorado

10:30AM H4.00001 Strong-field atomic physics in the Classical Limit\(^1\). LOUIS DIMAURU, The Ohio State University — Over the last decade, the tailoring of a light field for manipulating the dynamics of a system at the quantum level has taken a prevalent role in modern atomic, molecular and optical physics. As first described by Keldysh, the ionization of an atom by an intense laser field will evolve depending upon the light characteristics and atomic binding energy. Numerous experiments have thoroughly investigated the dependence of the intensity and pulse duration on the ionization dynamics of inert gas atoms. However, exploration of the wavelength dependence has been mainly limited to wavelengths less than 1 \(\mu\)m, or in the language of Keldysh to the multiphoton or mixed ionization regime. It is now technically possible to perform more thorough test, and perhaps exploit, the scaling laws at wavelengths greater than 1 \(\mu\)m. In addition, excitation with mid-infrared light augments a variety of atomic systems which will tunnel ionize, as well as posing different model atomic structure, e.g. one- and two-electron like systems. This talk will examine the implication of the strong-field scaling as it pertains to the production of high energy particles and the generation of attosecond pulses. We will interpret the intense laser-atom interaction using a semi-classical trajectory model.

1 DOE and NSF

11:00AM H4.00002 High harmonic spectroscopy and time-resolved holography with photoelectrons. MISHA IVANOV, Imperial College London — I will describe recent applications of high harmonic generation for tracking attosecond dynamics of electrons and holes in molecules, and our hopes to use photo-electron spectra for the same purpose. Interaction of intense infrared laser light with atoms and molecules leads to rich dynamics which presents unique combination of quantum and classical physics, ripe with unusual opportunities for imaging dynamics of electrons and nuclei at the time-scale from about 100 attoseconds to a few femtoseconds. As the infrared laser field strips an electron from an atom or a molecule, the electron starts to oscillate in the laser field. Energy \(E\) of these oscillations scales linearly with laser intensity \(I\) and quadratically with wavelength \(\lambda\) and can easily exceed 100 eV for typical experimental conditions. Re-encounter of the electron with the parent ion during such oscillations leads to several effects, including (i) high harmonic generation, which results from recombination of the returning electron with hole left in the ion, and (ii) electron parent-ion diffraction and electron holography, which results from electron-parent ion scattering. These processes encode spatial and temporal information about the parent ion. Spatial resolution can be better than an angstrom, courtesy of the electron de-Broglie wavelength. Temporal resolution can exceed 100 attoseconds, thanks to the dependence of the returning electron energy on the instant of its return: this energy changes from almost zero to the maximum value in less than half of the laser cycle \(T\) (\(T=2.6\) fsec for \(\lambda=800\) nm). I will first introduce the basic ideas underlying time-resolved electron holography and show recent proof-of-principle experimental results. The bulk of this talk will focus on high harmonic spectroscopy. The properties of high harmonic radiation - amplitude, phase, and polarization - encode detailed information about attosecond to femtosecond motion of electrons and light nuclei in the molecule. Experimental challenge is to completely characterize the emitted radiation, measuring not only light intensity but also phase and polarization. Theoretical challenge is to interpret the experimental data, taking into account highly nonlinear, non-perturbative nature of laser-induced dynamics. I will illustrate the potential of the technique by showing several examples of successful joint experimental and theoretical efforts, which gave us sometimes unexpected insight into core rearrangement during strong-field ionization. I will also show results of using high harmonic generation to time-resolve electron tunnelling from atoms and molecules.

11:30AM H4.00003 High Harmonic Spectroscopy with oriented molecules\(^1\). E. FRUMKER, Joint Attosecond Science Laboratory, University of Ottawa and National Research Council of Canada, N. KAJUMBA, Max-Plank Institute of Quantum Optics, J.B. BERTRAND, H.J. WORNER, C.T. HEBEISEN, Joint Attosecond Science Laboratory, University of Ottawa and National Research Council of Canada, P. HOCKETT, M. SPANNER, S. PATCHKOVSKII, Steacie Institute for Molecular Science, National Research Council of Canada, G.G. PAULUS, Department of Physics, Texas A&M University, D.M. VILLENEUVE, P.B. CORKUM, Joint Attosecond Science Laboratory, University of Ottawa and National Research Council of Canada, JASLAB TEAM — We report the first measurement of high harmonics from oriented gas samples. We show that attosecond and re-collision science provides a detailed and sensitive probe of molecular asymmetry. On each 1/2 cycle of an intense light pulse, laser-induced tunneling extracts an electron wave packet from the molecule. When the electron wave packet recombines, alternately from one side of the molecule or the other, its amplitude and phase asymmetry determines the even and odd harmonics radiation that it generates. We determine the phase asymmetry of the attosecond XUV pulses emitted when an electron recoiles from opposite sides of the CO molecule, and the phase asymmetry of the recollision electron just before recombination.

1 Marie Curie International Outgoing Fellowship

11:42AM H4.00004 High-order Harmonic Generation from Molecular Hydrogen. MICHAEL CHINI, XIAOWEI WANG, QI ZHANG, KUN ZHAO, YI WU, ZENGHU CHANG, CREOL and Department of Physics, University of Central Florida — High-order harmonics generated in molecular hydrogen gas by an 800 nm driving laser are compared to those generated in argon gas under the same driving laser intensity and gas pressure. We find that the yield of HHG from hydrogen gas is approximately an order of magnitude less than that of argon HHG although the ionization probabilities of the two gases are equal at intensities above \(3\times10^{14}\) W/cm\(^2\). We propose that the reduced HHG yield results from the low recombination cross-section of hydrogen.
11:54AM H4.00005 High Harmonic Generation in Laser-Assisted Radiative Attachment or Recombination Processes, ALEXANDER V. FLEGEL, Department of Physics and Astronomy, University of Nebraska, Lincoln, USA, ALEXANDER N. ZHELTUKHIN, MIKHAIL V. FROLOV, NIKOLAI L. MANAKOV, Department of Physics, Voronezh State University, Voronezh, Russia, ANTHONY F. STARACE, Department of Physics and Astronomy, University of Nebraska, Lincoln, USA. — Resonant enhancements are predicted in cross sections \( \sigma_n \) for laser-assisted radiative attachment or electron-ion recombination accompanied by absorption of \( n \) laser photons. These enhancements occur for incoming electron energies at which the electron can be attached or recombined by emitting \( \mu \) laser photons followed by emission of a spontaneous photon upon absorbing \( n + \mu \) laser photons. The close similarity between rescattering plateaus in spectra of resonant attachment/recombination and of high-order harmonic generation is shown on a general parametrization for \( \sigma_n \) and on numerical results for \( e^{-H} \) attachment.  

This work was supported in part by RFBR Grants No. 09-02-00541 and No. 10-02-00235, and by NSF Grant No. PHYS-0901673.

12:06PM H4.00006 Quantitative Measurement of Phase Matching Conditions in Higher Order Harmonic Generation, SUDIPTA MONDAL, FREDERIC CONDIN, PHILIPP KLAUS, CARLOS TRALLERO, Kansas State University, BENJAMIN WILSON, KRISTEN GOULD, ERWIN POLIAKOFF, Louisiana State University. — HHG has proven to be a very sensitive probe for the electronic structure of atoms and molecules. Since the generation of the harmonics is a macroscopic process, it depends on phase matching conditions. Macroscopic features of phase matching in high harmonics generation are poorly understood and also very difficult to maintain. In this paper we study phase matching in high harmonic generation quantitatively, so that harmonics can be used as an atomic and molecular probe. We measured HHG spectrum with varying laser intensity and focusing conditions. We also change the phase of the input beam by clipping it with an iris, changing it Gaussian to Bessel beam, and observe two regions of phase matching for Gaussian beam becomes one in case of Bessel beams.

12:18PM H4.00007 Visualizing electron wavepacket dynamics in a strong laser field, K. ELLEN KEISTER, DANIEL D. HICKSTEIN, PREDRAG RANITOVIC, PAUL ARPIN, XIBIN ZHOU, CRAIG W. HOGLE, BOSSHENG ZHANG, CHENGYUAN DING, MARGARET M. MURNANE, HENRY KAPTEYN, JILA, University of Colorado at Boulder, STEFAN WITTE, VU University, XIAO-MIN TONG, N. TOSHIMA, University of Tsukuba, YMKJE HUISMANS, FOM Institute AMOLF, MARC J.J. VRACKING, Max-Born-Institute, PER JOHNSON, Lund University. — Strong-field ionization, combined with 2D electron momentum imaging, has become a revolutionary tool for probing atomic and molecular structures on the femtosecond timescale. Major features apparent in intense-field photoelectron spectra have been shown to result from electrons scattered by the Coulomb potential that accumulate a different phase and interfere with electron trajectories that do not scatter. However, other features in these photoelectron spectra still remain to be explained. In this work, we use mid-infrared driving lasers to identify new structures in the low-energy photoelectron spectra from atoms, which can be unambiguously attributed to multiple sequential encounters of the laser-driven photoelectrons with the parent ion. This interpretation is obtained using a simple plane-spherical wave model, which provides physical insight into strong-field processes, and quantum-mechanical simulations validate this simple model. Reliably extracting structural information, especially dynamically changing molecules, requires a better understanding of the origin of all the photoelectron spectral features as a function of molecular excitation, orientation, and bond length.

Wednesday, June 6, 2012 10:30AM - 12:18PM  
Session H5 Unconventional Atom Trap Geometries

10:30AM H5.00001 Quantized decay of high charge superflow in an annular BEC, SCOTT BEATTIE, STUART MOULDER, ROB SMITH, NAAMAN TAMMUZ, ZORAN HADZIBABIC, University of Cambridge. — We have studied superfluid flow using a holographically generated Laguerre-Gauss (LG) beam to trap and rotate Bose-Einstein condensates of \( ^{87} \)Rb atoms. The LG beam allows phase windings with arbitrary choice of charge to be imprinted on the atomic cloud. The transferred angular momentum can be measured both interferometrically and mechanically. We have observed high charge vortices persist for long times (>40s) and decay stochastically in a quantized fashion. We also discuss our latest results on the application of artificial gauge potentials to our annular BEC.

10:42AM H5.00002 Driving phase slips in an annular Bose-Einstein condensate with a rotating weak link, KEVIN C. WRIGHT, R.B. BLAKESTAD, Joint Quantum Institute, NIST, University of Maryland, C.J. LOBB, University of Maryland, Department of Physics, W.D. PHILLIPS, G.K. CAMPBELL, Joint Quantum Institute, NIST. — We have created a toroidal atomic Bose-Einstein condensate, stirred by a rotating barrier potential which creates a weak link. Varying the rotation rate and critical current of the weak link, we observe two main regimes of behavior. At low rotation rates, and small critical current, we observe phase slips between well-defined persistent current states. At higher rotation rates, vortices penetrate into the bulk of the condensate, and discrete phase slips between well-defined persistent current states no longer occur. The response of the condensate can be compared to that of a superconducting ring with a weak link in an external magnetic field.

10:54AM H5.00003 Decay of a superfluid current of ultra-cold atoms in a toroidal trap, AMY MATHEY, Center for Optical Quantum Technologies and Institute of Laser Physics, University of Hamburg. — Using a numerical implementation of the truncated Wigner approximation, we simulate the experiment reported by Ramanathan et al., Phys. Rev. Lett. 106, 130401 (2011), in which a Bose-Einstein condensate is created in a toroidal trap and set into rotation via a Gauss-Laguerre beam. A potential barrier is then placed in the trap to study the decay of the superflow. We find that the current decays via thermally activated phase slips, which can also be visualized as a vortex moving across the barrier region in radial direction. Adopting the notion of critical velocity used in the experiment, we determine it to be lower than the local speed of sound at the barrier. This result is in agreement with the experimental findings, but in contradiction to the predictions of the Gross-Pitaevski equation.

11:06AM H5.00004 Cylindrical vector modes in tapered optical fibers for atom nanotrap, FREDRIK K. FATEMI, Naval Research Laboratory, JONATHAN E. HOFFMAN, Joint Quantum Institute, Dept. of Physics, UMD and NIST, College Park, MD 20742, SYLVAIN RAVETS, Laboratoire Charles Fabry, Institut d’Optique, CNRS Univ. Paris-Sud, France, GUY BEADIE, Naval Research Laboratory, LUIS A. OROZCO, L. LESTON, Joint Quantum Institute, Dept. of Physics, UMD and NIST, College Park, MD 20742. — Atoms confined to evanescent-field traps or lasers near tapered optical fibers are strongly coupled to photons propagating through the fiber. This strong coupling is ideal for quantum technologies and sensors. Previously, propagation and strong atom-photon interactions have been demonstrated in fibers with submicron diameters, small enough to admit only the HE\(_{11}\) mode. Higher order cylindrical vector modes, which have azimuthally-varying polarization profiles, open another set of trapping geometries in fibers with diameters slightly above the HE\(_{11}\) cutoff value. In this work, we discuss propagation experiments in tapered fibers that allow the first excited family of modes. We have observed stable transmission of the TE\(_{01}\), TM\(_{01}\), and HE\(_{21}\) modes in 1.2-micron-diameter fiber, currently with 25% throughput. Transmitted power and beam profiles monitored during the drawing process show interesting power exchange between core and cladding modes, and by adjusting the drawing parameters we have experimentally probed the propagation behavior. Work supported by ONR, ARO, the Fullbright Foundation and the NSF through the PFC at JQI.
than the recently published result of Nataraj et al. as tested our methodology on other parity conserving quantities. We find the EDM enhancement factor of Tl to be equal to −EDM enhancement factor K in Tl. We have carried out several calculations by different high-precision methods, studied previously omitted corrections, as well as implemented with a thermal sample of laser cooled rubidium atoms. The atoms are confined using what we call free-space atom chips, a novel optical dipole trap. Frequency spectroscopy measures the speed of sound in the toroidal channel and corrugations of the potential. We demonstrate a proof-of-concept sonic rotation sensor that is fairly insensitive to errors in the optical potential and density effects.

11:42AM H5.00007 Berry-gauge tuned Bose-Einstein condensate gyroscope1, RUDRA KAFLE, Worcester Polytechnic Institute, EDDY TIMMERMANS, Los Alamos National Laboratory — If stable, the many-body ground state of a dilute gas of ultra-cold, bosonic atoms occupying a superposition of two internal states is a Bose-Einstein condensate (BEC) of effective spin 1/2 bosons. The superfluid BEC dynamics admits long-lived quantized vortex states in which the complex phase of the superfluid order parameter, which we call the charge phase, undergoes an integer number of 2π windings along a multiply connected path - a closed trajectory that encloses a region in which the superfluid density vanishes. In response to an overall rotation of the ring, a quantization event can occur which can be used to sense rotation. Unfortunately, the sensitivity of the ring BEC gyroscope would be limited as the quantization event sets in at a rotation frequency that is not as low as the frequencies measured by other devices such as ring laser gyroscopes. We show that the recently realized synthetic magnetic fields, in which the controlled position dependence of the spin results in an effective gauge field, can tune the BEC ring gyroscope to trigger a quantization event at much smaller rotation frequency. In addition, the effective gauge field can undergo its own quantization events in which the spin vector undergoes an integer number of 2π or 4π windings.

1) LDRD program and CNLS, LANL

11:54AM H5.00008 Fundamental Atomtronic Circuit Elements, JEFFREY LEE, BRIAN McILVAIN, CHRISTOPHER LOBB, WENDELL T. HILL III, Joint Quantum Institute, University of Maryland, College Park, MD 20742 USA — Recent experiments with neutral superfluid gases have shown that it is possible to create atomtronic circuits analogous to existing superconducting circuits. The goals of these experiments are to create complex systems such as Josephson junctions. In addition, there are theoretical models for active atomtronic components analogous to diodes, transistors and oscillators. In order for any of these devices to function, an understanding of the more fundamental atomtronic elements is needed. Here we describe the first experimental realization of these more fundamental elements. We have created an atomtronic capacitor that is discharged through a resistance and inductance. We will discuss a theoretical description of the system that allows us to determine values for the capacitance, resistance and inductance. The resistance is shown to be analogous to the Sharvin resistance, and the inductance analogous to kinetic inductance in electronics. This atomtronic circuit is implemented with a thermal sample of laser cooled rubidium atoms. The atoms are confined using what we call free-space atom chips, a novel optical dipole trap produced using a generalized phase-contrast imaging technique. We will also discuss progress toward implementing this atomtronic system in a degenerate Bose gas.

12:06PM H5.00009 Conduction of Ultracold Fermions Through a Mesoscopic Channel, DAVID STADLER, JEAN-PHILIPPE BRANTUT, JAKOB MEINEKE, SEBASTIAN KRINNER, TILMAN ESSLINGER, Institute for Quantum Electronics, ETH Zurich, QUANTUM OPTICS TEAM — In a mesoscopic conductor electric resistance is detected even if the device is defect-free. We engineer and study a cold-atom analog of a mesoscopic conductor. It consists of a narrow channel connecting two macroscopic reservoirs of fermions that can be switched from ballistic to diffusive. We induce a current through the channel and find ohmic conduction, even for a ballistic channel. An analysis of in-situ density distributions shows that in the ballistic case the dissipation is localized at the entrance and exit of the channel, revealing the presence of contact resistance. In contrast, a diffusive channel with disorder displays dissipation over the whole channel. Our approach opens the way towards quantum simulation of mesoscopic devices with quantum gases.

Wednesday, June 6, 2012 10:30AM - 12:30PM –
Session H6 Symmetry Tests and Electric Dipole Moment Measurements

10:30AM H6.00001 ABSTRACT MOVED TO U1.00004 –

10:42AM H6.00002 ABSTRACT WITHDRAWN –

10:54AM H6.00003 Electric dipole moment enhancement factor of thallium1, SERGEY PORSEV, University of Delaware and Petersburg Nuclear Physics Institute, MARIANNA SAFRONOVA, University of Delaware, MIKHAIL KOZLOV, Petersburg Nuclear Physics Institute — A number of extensions of the standard model of particle physics predict electric dipole moments (EDM) of particles that may be observable with the present state-of-the art experiments. The EDMs arise from the violations of both parity and time-reversal invariance. The electron EDM is enhanced in certain atomic and molecular systems. One of the most stringent limits on the electron EDM δ_e was obtained from the experiments with 205Tl: δ_e < 1.6 \times 10^{-18} \text{ cm} [Regan et al., PRL 88, 071805 (2002)]. This result crucially depends on the calculated value of the effective electric field on the valence electron. In the case of Tl this effective field is proportional to the applied field E_0: E_{eff} = K E_0. The goal of this work is to resolve the present controversy in the value of the EDM enhancement factor K in Tl. We have carried out several calculations by different high-precision methods, studied previously omitted corrections, as well as tested our methodology on other parity conserving quantities. We find the EDM enhancement factor of Tl to be equal to −573(20). This value is 20% larger than the recently published result of Nataraj et al. [PRL 106, 200403 (2011)] but agrees very well with several earlier results.

1) NSF and RFBR
We report on recent progress on a search for the electron’s electric dipole moment (eEDM) using solid-state Eu standing wave ODT suitable for the EDM measurement. In the near future, we plan to optically pump and observe nuclear spin precession. This research is the EDM of radium-225, which is expected to be abnormally large compared to other species. Neutral cold radium atoms are loaded from a magneto-optic beam property, including the flux and internal temperature, are characterized. The hyperfine structure and the lambda doublet of the transition are measured.

searching for the eEDM in the metastable H\(^2\) molecule and using laser induced fluorescence spectroscopy to detect the molecules through spectrums. New dipole moments and spectroscopic constants for the A state are presented. With these new data we have isolated an e-EDM sensitive Stark transition at a magic electric field that both polarizes the molecule and allows for sharp transitions that are immune to variations in electric field.

This work is supported by the National Science Foundation and the University of Oklahoma’s Office of the Vice President for Research.

11:30AM H6.00006 Design and Construction of an Electron Electric Dipole Moment Experiment Using Thorium Monoxide\(^1\)  
BENJAMIN SPAUN, PAUL HESS, NICK HUTZLER, ELIZABETH PETRIK, JOHN DOYLE, GERALD GABRIELSE, Harvard University, CHEONG CHAN, EMIL KIRILOV, BRENDON O’LEARY, DAVID DEMILLE, Yale University, ACME COLLABORATION  
Observation of an electron electric dipole moment (eEDM) would imply new sources of CP violation beyond the Standard Model. By measuring spin precession signals on a cryogenic molecular beam, the ACME collaboration is searching for the eEDM in the metastable H\(^2\) state of thorium monoxide. We discuss the design and completed assembly of the first generation of this experiment. Precise electric and magnetic field sources, magnetic shields, and a fluorescence collection system have been constructed and installed, and the molecule beam source has been optimized. With this system we have begun collecting and analyzing eEDM data.

1Work supported by the NSF.


11:42AM H6.00007 Towards Improvements to the Statistical Sensitivity of the ACME Electron EDM Experiment  
NICHOLAS HUTZLER, PAUL HESS, Harvard University, EMIL KIRILOV, BRENDON O’LEARY, Yale University, ELIZABETH PETRIK, BENJAMIN SPAUN, Harvard University, DAVID DEMILLE, Yale University, GERALD GABRIELSE, JOHN DOYLE, Harvard University, ACME COLLABORATION  
Construction of the first generation ACME experiment [A. C. Vutha et al., J. Phys. B 43, 074007 (2010)] to measure the electron electric dipole moment (eEDM) has been completed, and data acquisition and analysis are currently underway. In order to further increase our statistical sensitivity, several improvements are being developed and implemented. We report on: progress towards increasing our total molecule flux with a new beam source; utilizing microwaves, optical pumping, and electrostatic beam focusing to increase the molecule flux in a single state; efficient state preparation via STIRAP; improving detection efficiency by photon cycling; and apparatus redesign to allow more efficient fluorescence collection.

11:54AM H6.00008 Optical Spectroscopy of Tungsten Carbide Molecules for Permanent Electron Electric Dipole Moment Search  
JEONGWON LEE, JINHAI CHEN, AARON LEANHARDT, University of Michigan — Searching for a permanent electron electric dipole moment (EDM) is a powerful tool to probe for physics beyond the Standard Model. We identify the X^3\(\Delta\) ground state of tungsten carbide molecules as a candidate system for the electron EDM search. We have developed a molecular beam source from pulse supersonic expansion technique and used laser induced fluorescence spectroscopy to detect the molecules through \([20/\hbar]v = 2, v’ = 4 \rightarrow X^3\(\Delta\), v’ = 0 transition. The beam properties, including the flux and internal temperature, are characterized. The hyperfine structure and the lambda doublet of the transition are measured and the implications related to the EDM experiment are revealed.

12:06PM H6.00009 Towards an EDM Measurement in Radium-225  
MATTHEW DIETRICH, K. BAILEY, J. GREENE, R. HOLT, Argonne National Lab, M. KALITA, W. KORSCH, University of Kentucky, Z.-T. LU, P. MUELLER, T. O’CONNOR, R. PARKER, J. SINGH, Argonne National Lab — The existence of an atomic electric dipole moment (eEDM) would violate both the time and parity symmetries of nature, and so the measurement of one would give a valuable window into physics beyond the standard model. Here we describe recent progress towards measurement of the EDM of radium-225, which is expected to be abnormally large compared to other species. Neutral cold radium atoms are loaded from a magneto-optic beam and transferred into an optical dipole trap (ODT), which is mechanically translated to move the radium into the science region. We then transfer the atoms to a second, standing wave ODT suitable for the EDM measurement. In the near future, we plan to optically pump and observe nuclear spin precession. This research is supported by DOE, Office of Nuclear Physics contract No. DE-AC02-06CH11357.

12:18PM H6.00010 Progress towards an electron electric dipole moment search in Europium-Barium Titinates  
STEPHEN ECKEL, Yale University, ALEXANDER SUSHKOV, Harvard University, STEVEN LAMOREAUX, Yale University — We report on recent progress on a search for the electron’s electric dipole moment (eEDM) using solid-state Eu\(^{5+}\)B\(^{6+}\)Ti\(^{4+}\). This material has many desirable properties including ferroelectricity below 200 K and paramagnetism above 1.8 K. When the sample has a non-zero electric polarization, the seven unpaired 4f electrons of the Eu\(^{2+}\) ions in the lattice feel a large effective electric field of order 10 MV/cm in the direction of the polarization. This causes the electron spins to align with the electric polarization and generate a magnetization, which is measured using DC SQUID magnetometers. We will detail measurements of systematic effects along with recent results toward a measurement of the eEDM.

Wednesday, June 6, 2012 10:30AM - 12:30PM  
Session H7 Quantum Computing I — Terrace - Chair: Chris Monroe, University of Maryland and JQI
10:30AM H7.00001 Quantum simulation of the transverse field antiferromagnetic Ising model with trapped ions. SIMCHA KORENBLIT, WES CAMPBELL, EMILY EDWARDS. Joint Quantum Institute, University of Maryland- College Park, ZHEXUAN GONG, University of Michigan, Ano Arbor, DIVIR KAFRI, KIHWAN KIM, RAJIBUL ISLAM, AARON LEE, JACOB SMITH. Joint Quantum Institute, University of Maryland- College Park, JOSEPH WANG, Georgetown University, LUMING DUAN, University of Michigan, Ann Arbor, JIM FREERICKS, Georgetown University, JUNSANG KIM, Duke University, CHRIS MONROE, Joint Quantum Institute, University of Maryland- College Park — We simulate a long range quantum Ising model with a chain of Yb-171\textsuperscript{+} ions, with two ground states in the hyperfine manifold representing the spin-1/2 states. The Ising interactions are generated by phonon mediated stimulated Raman excitations, and can be tuned in strength and sign by selectively controlling the coupling to various vibrational normal modes. We have recently observed emergence of a quantum phase transition and ferromagnetism due to the interplay of Ising interactions and an effective transverse magnetic field. In our current effort, we simulate long range antiferromagnetic couplings which potentially lead to spin frustration, and investigate the nature of spin ordering as we vary the range of the interaction. We are also investigating the generation of more exotic Ising graphs, even in 2D, by controlling the spectrum of the Raman lasers.

10:42AM H7.00002 Engineering 2D Ising Interactions in a Large (N>100) Ensemble of Trapped Ions\footnote{This work supported by the DARPA-OLE program.}. BRIAN SAWYER, JOSEPH BRITTON, NIST-Boulder, CO, ADAM KEITH, NCSU, Raleigh, NC, JOSEPH WANG, JAMES FREERICKS, Georgetown University, HERMANN UYNS, CSIR, South Africa, MICHAEL BIERCUK, University of Sydney, JOHN BOLLINGER, NIST-Boulder, CO — Experimental progress in atomic, molecular, and optical physics has enabled exquisite control over ensembles of cold trapped ions. We have recently engineered long-range Ising interactions in a two-dimensional, 1-mK Coulomb crystal of hundreds of \textsuperscript{138}Ba\textsuperscript{+} ions confined within a Penning trap. Interactions between the \textsuperscript{138}Ba\textsuperscript{+} valence spins are mediated via spin-dependent optical dipole forces (ODFs) coupling to transverse motional modes of the planar crystal. A continuous range of inverse-power-law spin-spin interactions from infinite (1/r\textsuperscript{2}) to dipolar (1/r\textsuperscript{3}) are accessible by varying the ODF drive frequency relative to the transverse modes. The ions naturally form a triangular lattice structure within the planar array, allowing for simulation of spin frustration using our generated antiferromagnetic couplings. We report progress toward simulating the ferromagnetic/antiferromagnetic transverse quantum Ising Hamiltonians in this large ensemble. We also report spectroscopy, thermometry, and sensitive displacement detection (~100 pm) via entanglement of valence spin and drumhead oscillations.

11:06AM H7.00004 A quantum phase transition in a quantum external field: The formation of a Schrodinger magnet\footnote{Supported by the Darpa OLE program and the Army Research Office under grant number W911NF0710576}. BOGDAN DAMSKI, Los Alamos National Laboratory, MAREK RAMS, University of Vienna, MICHAEL ZWOLAK, Oregon State University — Recent developments in manipulations of trapped ions allow for simulation of various spin models in ion chains (S. Korenblit et al., e-print arXiv:1201.0776). This motivates our work on novel types of quantum phase transitions, whose experimental studies could not have been performed in traditional condensed matter systems due to insufficient level of control. We focus on an Ising lattice undergoing a quantum phase transition in a quantum magnetic field. Such a field can be emulated by coupling the lattice to a central spin initially in a superposition state. We show that, by adiabatically driving such a system, one can prepare a quantum superposition of any two ground states of the Ising lattice. In particular, one can end up with the Ising lattice in a superposition of ferromagnetic and paramagnetic phases, a scenario with no analogue in prior studies of quantum phase transitions. Remarkably, the resulting magnetization of the lattice encodes the position of the critical point and universal critical exponents, as well as the ground state fidelity. The model that we study can be emulated in an ion chain. This research is summarized in M.M. Rams, M. Zwolak, and B. Damski, arXiv:1201.1932 (2012).

11:18AM H7.00005 Ion-photon entanglement and state mapping in an optical cavity. TRACY E. NORTHP, ANDREAS STUTE, BERNARDO CASABONE, BIRGIT BRANDSTÄTTER, KonSTANTIN FRIEBE, RAINER BLATT\footnote{Supported by U.S. Department of Energy through the LANL/LDRD Program.}. Institute for Experimental Physics, University of Innsbruck — Quantum networks require a coherent interface between quantum states of light and matter. In order to realize such an interface, we couple a single calcium ion to two orthogonal polarization modes of a high-finesse optical resonator. Trapped ions have the advantage of well-developed techniques for coherent state manipulation and readout, while the cavity setting enables an efficient mapping process. We demonstrate on-demand, high-fidelity entanglement between an ion and a photon. Both amplitude and phase of the entangled state are fully tunable due to the use of a bichromatic Raman field. In contrast to previous work, the phase of the entangled state is independent of the photon detection time. In a second step toward cavity-based quantum networks, an ion is prepared in a superposition state, and this state is mapped coherently onto a photon, with characterization via process tomography. Finally, prospects for single-ion strong coupling are discussed.

11:30AM H7.00006 Integrated Cavity QED in a linear Ion Trap Chip for Enhanced Light Collection. FRANCISCO BENITO, Sandia National Laboratories - University of New Mexico, STERK JONATHAN, Sandia National Laboratories, TABAKOV BOYAN, Sandia National Laboratories - University of New Mexico, RAYMOND HALTLI, CHRIS TIGGES, DANIEL STICK, MATTHEW BALIN, DAVID MOEHRING, Sandia National Laboratories — Realizing a scalable trapped-ion quantum information processor may require integration of tools to manipulate qubits into trapping devices. We present efforts towards integrating a 1 mm optical cavity into a microfabricated surface ion trap to efficiently connect nodes in a quantum network. The cavity is formed by a concave mirror and a flat coated silicon mirror around a linear trap where ytterbium ions can be shuttled in and out of the cavity mode. By utilizing the Purcell effect to increase the rate of spontaneous emission into the cavity mode, we expect to collect up to 13\% of the emitted photons. This work was supported by Sandia’s Laboratory Directed Research and Development (LDRD) and the Intelligence Advanced Research Projects Activity (IARPA). Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the US Department of Energy’s National Nuclear Security Administration under contract DE-AC04-94AL85000.
11:42AM H7.00007 Ultrafast spin-motion entanglement and interferometry in single atomic qubits1, CRYSTAL SENKO, JONATHAN MIZRAHI, WESLEY C. CAMPBELL, KALE G. JOHNSON, Joint Quantum Institute, University of Maryland Department of Physics and National Institute of Standards and Technology, College Park, Maryland 20742 — We report entanglement between the hyperfine spin state and motional dynamics of a single atom on a timescale of 15 ns. We extract single pulses from a picosecond mode-locked laser and split them into short pulse trains tailored to create the desired spectrum by tuning the relative delays and frequency shifts appropriately. The resulting interaction imparts a momentum transfer of 2\hbar to each of the two spin states in opposite directions. We apply pairs of momentum kicks to create an interferometer and probe the collapse and revival of spin coherence as the motional wavepacket is split and recombined. This technique holds promise for applications such as interferometry [1] and scalable entangling gates [2,3].


1This work is supported by grants from the U.S. Army Research Office with funding from the DARPA OLE program, IARPA, and the MURI program; the NSF PIF Program; the NSF Physics Frontier Center at JQI; and the European Commission AQUTE program.

11:54AM H7.00008 Multi-pulse compensation sequences for quantum information processing with trapped ions, S. CHARLES DORET, Georgia Tech Research Institute, TRUE MERRILL, KENNETH BROWN, Georgia Institute of Technology, ALEXA HARTER, Georgia Tech Research Institute — Now that the basic components of a trapped ion quantum information processor have all been demonstrated, many recent experiments have focused on scaling systems to larger numbers of qubits to permit the execution of classically intractable quantum algorithms/simulations. Microfabricated surface electrode ion traps offer one avenue for scaling to more qubits, allowing for the stable trapping of long chains of many ions. However, the small spacing between ions required for strong coupling makes the single-qubit laser addressing needed for arbitrary gate operations extremely challenging. Although such addressing is possible using tightly focused lasers, focusing requires cumbersome multi-element lenses and is highly sensitive to pointing instabilities. Transporting the target ion away from its neighbors is another option but is time consuming and may cause motional heating. Multi-pulse passband compensation sequences offer an appealing alternative that can simultaneously correct for errors in pulse amplitude and duration while reducing the effects of laser bleed-through to neighboring ions. Here we report on experimental progress toward the use of such pulse sequences for individual addressing of $^{40}\text{Ca}^{+}$ ions without the use of complicated optics.

12:06PM H7.00009 Trapping ions in a segmented ring trap, B.P. TABAKOV, J.D. STERK, F. BENITO, R. HALTLI, C.P. TIGGES, D. STICK, M.G. BLAIN, D.L. MOEHRING, Sandia National Laboratories, Albuquerque NM 87123 — We demonstrate robust trapping in an ion trap which has a ring shaped RF node. Ions are back-side loaded through a small 10 \mu m diameter loading hole and we have demonstrated thousands of complete circuits around the trap. Each circuit passes through 44 trapping zones; the trap has 89 independent DC control electrodes. Measurements of the tangential secular frequency indicate a weak dependence on the RF and the loading hole. The ion trap is fabricated using four metal layers, allowing for the inner isolated electrodes to be electrically routed underneath the trap with negligible effects on the trapped ions.

This work was supported by the Intelligence Advanced Research Projects Activity (IARPA). Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the US Department of Energy’s National Nuclear Security Administration under contract DE-AC04-94AL85000.

12:18PM H7.00010 ABSTRACT WITHDRAWN — Wednesday, June 6, 2012 2:00PM - 3:48PM — Session J1 Focus Session: Two-Dimensional Fermi Gas Grand Ballroom BCD - Chair: Kaden Hazzard, JILA and University of Colorado

2:00PM J1.00001 Two-dimensional Fermi Gases, MICHAEL KOEHL, University of Cambridge — Pairing of fermions is ubiquitous in nature and it is responsible for a large variety of fascinating phenomena like superconductivity, superfluidity of 3He, the anomalous rotation of neutron stars, and the BEC-BCS crossover in strongly interacting Fermi gases. When confined to two dimensions, interacting many-body systems bear even more subtle effects, many of which lack understanding at a fundamental level. Most striking is the, yet unexplained, effect of high-temperature superconductivity in cuprates, which is intimately related to the two-dimensional geometry of the crystal structure. In particular, the questions how many-body pairing is established at high temperature and whether it precedes superconductivity are crucial to be answered. We report on the observation of pairing in trapped two-dimensional atomic Fermi gas in the regime of strong coupling. We perform momentum-resolved photoemission spectroscopy to measure the spectral function of the gas and we detect a many-body pairing gap above the superfluid transition temperature. Moreover, using the same technique, we investigate spin-imbalanced Fermi gases and find evidence for the formation of polarons and their crossover to a dimer state in two dimensions. Our observations mark a significant step in the emulation of layered two-dimensional strongly correlated superconductors using ultracold atomic gases.

2:30PM J1.00002 Clock shift in a strongly interacting two-dimensional Fermi gas1, CHRISTIAN LANGMACK, The Ohio State University, MARCUS BARTH, WILHELM ZWERGER, Technische Universität München, ERIC BRAAET, The Ohio State University — We derive universal relations for the radio-frequency (rf) spectroscopy of a two-dimensional Fermi gas containing spin states interacting through an S-wave scattering length. The rf transition frequency has a high-frequency tail that is proportional to the contact and displays logarithmic scaling violations, decreasing asymptotically like $1/(\omega^2 \ln \omega)$. Its coefficient is proportional to $\ln^2(a'_{\text{D}}/a_{\text{D}})$, where $a_{\text{D}}$ and $a'_{\text{D}}$ are the 2-dimensional scattering lengths associated with initial-state and final-state interactions. The clock shift is proportional to the contact and to $\ln(a'_{\text{D}}/a_{\text{D}})$. If $|\ln(a'_{\text{D}}/a_{\text{D}})| > 1$, the clock shift arises as a cancellation between much larger contributions proportional to $\ln^2(a'_{\text{D}}/a_{\text{D}})$ from bound-bound and bound-free rf transitions.

1Army Research Office and Air Force Office of Scientific Research and DFG

2:42PM J1.00003 Scale invariance and viscosity of a two-dimensional Fermi gas, ENRICO VOGT, MICHAEL FELL, BERNER FRÖHLICH, DANIEL PERTOT, MARKO KOSCHORRECK, MICHAEL KÖHL, University of Cambridge, UK — We investigate the collective excitations of a harmonically trapped two-dimensional Fermi gas from the collisionless to the hydrodynamic regime. In the experiment we create two-dimensional Fermi gases of $^{40}\text{K}$ atoms by using an optical lattice. Interactions are tuned by applying a magnetic field close to the Feshbach resonance. We observe the existence of a breathing mode at twice the trap frequency, which is invariant against interaction strength, amplitude of the excitation, and temperature. Moreover, this breathing mode is undamped as compared to the dipole mode, which provides evidence for a $SO(2,1)$ scaling symmetry of the two-dimensional Fermi gas. In addition, we investigate the quadrupole mode to measure the shear viscosity of the two-dimensional gas and study its temperature dependence.
2:54PM J1.00004 Evolution of Fermion Pairing from Three to Two Dimensions1, MARTIN ZWIERLEIN, Massachusetts Institute of Technology — The behavior of interacting fermions in two dimensions has long been of great interest. Unconventional superconductivity in high-transition-temperature superconductors arises in the two-dimensional cooper-oxide planes, with only weak intralayer coupling. Layered organic conductors and certain heavy-fermion superconductors also feature a quasi-2D structure, with strongly anisotropic conductivity. In two dimensions, the scale of thermal and quantum fluctuations is enhanced, destroying long-range order and leading to algebraic decay of the order parameter. On the other hand, in quantum mechanics, two particles in vacuum with arbitrarily weak interactions may still bind in two dimensions, while binding of weakly interacting fermions in three dimensions requires a many-body effect, Cooper pairing. It is thus interesting to ask whether superconductivity or superfluidity is enhanced somewhere in between two and three dimensions. In recent years, experiments on ultracold gases of fermionic atoms in three dimensions have allowed access to the crossover from Bose-Einstein condensation (BEC) of tightly-bound fermion pairs to Bardeen-Cooper-Schrieffer (BCS) superfluidity of long-range Cooper pairs. Such a fermion pair superfluid loaded into a periodic potential should form stacks of two-dimensional superfluids with tunable interlayer coupling, an ideal model for Josephson-coupled quasi-2D superconductors. For deep potentials in the regime of uncoupled 2D layers, increasing the temperature of the gas is expected to destroy superfluidity through the Berezinskii-Kosterlitz-Thouless mechanism, while more exotic multi-plane vortex loop excitations are predicted for a 3D-anisotropic BCS superfluid near the critical point. In this talk we present our recent experiments, where we follow the evolution of fermion pairing in the dimensional crossover from 3D to 2D as a strongly interacting Fermi gas of $^6$Li atoms becomes confined to a stack of two-dimensional layers formed by a one-dimensional optical lattice. Decreasing the dimensionality leads to the opening of a gap in radio-frequency spectra, even on the Bardeen-Cooper-Schrieffer side of a Feshbach resonance. The measured binding energy of fermion pairs closely follows the theoretical prediction for the binding of two particles in isolation. In the two-dimensional limit, it is in surprising agreement with zero-temperature mean-field BEC-BCS crossover theory that predicts the energy threshold for radio-frequency dissociation to lie at the two-body binding energy.

1This work was supported by the NSF, AFOSR, ONR YIP, DARPAFA, ARO with funding from the DARPA OLE program, and the David and Lucile Packard Foundation.

3:24PM J1.00005 Two-dimensional attractive Fermi gases’ excitations and radio-frequency spectra across the BEC/BCS crossover, KADEN HAZZARD, JILA, NIST, and University of Colorado-Boulder — We calculate the radio-frequency spectra of two-dimensional attractive Fermi gases, including final state interactions, motivated by recent measurements by the groups of Koehl, Thomas, and Zwierlein. The calculation includes coherent excitations generated by the radio-frequency probe on top of the mean field solution. We find that although the gap is identical to the two particle theory, spectral shapes are modified both by many-body effects and by final state interactions. We compare these shapes to experimental measurements.

3:36PM J1.00006 Observation of polaron-to-polaron transitions in the radio-frequency spectra of a quasi-two-dimensional Fermi gas, YINGYI ZHANG, WILLIE ONG, ILYA ARAKELYAN, Duke University, NC State University, JOHN THOMAS, NC State University — We measure radio-frequency spectra for a two-component mixture of a $^6$Li atomic Fermi gas in a quasi-two-dimensional trapping potential. We study the many-body regime, where the Fermi energy is comparable to the energy level spacing in the tightly confined direction. BCS theory predicts that the spectra should be determined by dimer transitions. Well below the Feshbach resonance, we observe spectra due to molecular dimers. However, near the Feshbach resonance, we find that the observed resonances do not correspond to the predicted transitions between confinement-induced dimers. Instead, the spectra appear to be well-described by transitions between noninteracting polaron states in two dimensions.

Wednesday, June 6, 2012 2:00PM - 4:00PM —
Session J2 Novel Techniques for Cold Atoms Grand Ballroom GF - Chair: Cass Sackett, University of Virginia

2:00PM J2.00001 Characterization and manipulation of a high-magnetic field trap, ERIC PARADIS, GEORG RAITHEL, University of Michigan — We report on the characterization of an efficient atom trap within a background magnetic field of 2.6 Tesla. Up to $10^8$ Rubidium atoms are recaptured from a cold atomic beam with a 2-3% collection efficiency, in a cigar-shaped volume and cooled with a six-beam optical molasses. The aspect ratio of the trap is measured as a function of the magnetic field curvature, which can be varied to produce a range of trap shapes. The trapping lineshape is both narrow and asymmetric, as is characteristic of laser-cooling of atoms or ions in an external trapping potential. Additional features of the high magnetic field trap include cooling onto hollow shell-like structures. Simulation results are also presented.

2:12PM J2.00002 Towards ultracold single neutral atoms in microscale optical dipole traps, ADAM KAUFMAN, BRIAN LESTER, CINDY REGAL, JILA, University of Colorado at Boulder, UCB 440, Boulder, CO 80309 — We seek to create a small array of single neutral atoms laser-cooled to their motional ground state in micrometerscale optical dipole traps. Experiments in such traps have demonstrated versatile capabilities in quantum logic and atom-light coupling, but to-date the atomic motion has often been uncontrolled and limiting. By cooling atoms in a few movable traps created with a high numerical aperture lens we envision abilities such as: Studying small arrays of interacting atoms with individual initialization of motion and spin, and coupling localized atoms to submicron optical modes. We present our initial studies of trapping and laser cooling a single $^{87}$Rb atom.

2:24PM J2.00003 A passively pumped cell for cold and ultracold atoms1, K.J. HUGHES, A. BROWN, Triad Technology, Inc., T. ARPORTNTH, C.A. SACKETT, University of Virginia — The demanding vacuum environment required by many techniques in AMO physics is one barrier to commercialization of these technologies. Even some research applications are hampered by the magnetic and electrical interference coming from conventional vacuum pumps and metal vacuum fittings. To help address these problems, we have developed an ultra-high vacuum cell that uses only passive pumping techniques and requires a minimal amount of metal. Vacuum in the cell was adequate to implement a rubidium magneto-optical trap and to maintain it over an extended period of time without active pumping. The demonstrated cells are simple and very compact, but a wide variety of configurations can be manufactured using similar techniques. We will present our results and discuss strategies for the future direction of this research.

1Supported by the US Navy SBIR program.

2:36PM J2.00004 Optical bichromatic forces for enhancing the number of trapped atoms1, JOSHUA GROSSMAN, ADAM HAMMETT, Department of Physics, St. Mary’s College of Maryland, St. Mary’s City, MD, FRANCESCO NARDUCCI, EO Sensors Division, Naval Air Warfare Center - Aircraft Division, Patuxent River, MD — Many applications of cold, trapped atoms would benefit from an increased number of atoms. Fieldable devices, such as sensors, need to be small. Because the number of trapped atoms scales as the fourth power of the trapping beam, reducing the size of the laser beams used in a magneto-optical trap leads to a large reduction in the number of trapped atoms. A larger optical force can potentially compensate for the reduction in stopping distance. Bichromatic forces rely on absorption followed by stimulated emission and, as such, they are in principle limited only by laser intensity. While bichromatic forces have been applied for cooling in one dimension, we present here our work toward using bichromatic forces for both cooling and trapping in three dimensions.

1Supported by the Office of Naval Research
2:48PM J2.00005 Loading and high efficiency evaporative cooling to BEC with a MACRO-FORT. ABRAHAM OLSON, ROBERT NIFFENEGGER, YONG P. CHEN, Purdue University — We present modeling and experimental results for efficient evaporative cooling in all-optical BEC experiments. By employing a misaligned cross-beam far off-resonance optical dipole trap (MACRO-FORT) we achieve decreasing trap depth with increasing average trap frequency during the evaporative cooling process, allowing highly efficient runaway evaporation. This method is effective even with a low initial atom density, and it has experimentally allowed us to create BECs of $^{87}$Rb starting from only a few $10^5$ atoms initially in the optical trap before evaporation. We have also studied the direct loading of $^{87}$Rb atoms from a MOT to our 1550nm optical trap, where the atomic D2 transition has a significant AC Stark shift.


3:00PM J2.00006 Trapping atoms in a bottle beam generated by a diffractive optical element\textsuperscript{1}, V. IVANOV, J. ISAACS, M. SAFFMAN, University of Wisconsin, S.A. KEMME, G.R. BRADY, A.R. ELLI\textsuperscript{s}, J.R. WENDT, Sandia National Labs — Highly excited Rydberg states have been used to demonstrate a neutral atom quantum gate, two-atom entanglement and hold promise for studies of surface potentials, such as the Casimir-Polder potential. Blue detuned Optical Bottle Beam (BoB) traps where atoms are confined in intensity minima trap both ground and Rydberg state atoms. This minimizes qubit decoherence and allows accurate measurements of the frequencies of the Rydberg transitions. We have generated optical bottle beam traps using a segmented diffractive optical element with $\pi$ phase shift between the inner and outer regions. The idea for this trap follows the approach used by Ozeri, et al. Phys. Rev. A 59, R1750 (1999) but integrates the phase shift and focusing lens into a single diffractive element fabricated at Sandia National Lab. Measured profiles of the trap light intensity are compared with numerical predictions using a Fresnel diffraction code. Progress towards atom trapping in the bottle for studies of atom-surface interactions will be presented.

\textsuperscript{1}This work was supported by Sandia National Laboratory

3:12PM J2.00007 Study of mesoscopic clouds of cold atoms in the interacting regime\textsuperscript{1}, RONAN BOURGAIN, ANDREAS FUHRMANEK, JOSEPH PELLEGRINO, YVAN R.P SOITSAIS, ANTOINE BROWAES, Laboratoire Charles Fabry – Institut Optique – CNRS, Palaiseau France — We present studies on cold and dense atomic $^{87}$Rb clouds containing $N \sim 2 - 100$ interacting atoms. We produced such mesoscopic ensembles by using a microscopic optical dipole trap from a MOT. Due to 2-body light-assisted collisions, we have found that in steady state such ensembles exhibit reduced number fluctuations with respect to a Poisson distribution. For $N \geq 2$, we measured a reduction Fano factor $F = 0.72 \pm 0.07$ consistent with the value $F = 3/4$ predicted at large $N$ by a general stochastic model \[1,2\]. To enhance interactions between the atoms, we are following two tracks. Firstly we evaporatively cooled a few hundreds of trapped atoms and obtained $\sim 10$ atoms close to quantum degeneracy $(n\lambda_{ab}^2 \sim 1)$ in the microscopic trap. In this regime s-wave interactions dominate $(n = 2 \times 10^{14} \text{ cm}^{-3})$. Secondly we sent near resonant light $(\lambda_r)$ on the small cloud (size l). When $l < \lambda_r/2\pi$, dipole-dipole interactions should lead to collective behaviour.


3:24PM J2.00008 See-saw Doppler cooling of three-level atoms by coherent pulse trains\textsuperscript{1}, MAHMOUD AHMED, EKATERINA ILINOVA, ANDREI DEREVIANKO, University of Nevada at Reno — We explore the feasibility of decelerating and Doppler cooling an ensemble of three-level $\Lambda$-type atoms by a coherent train of ultrashort laser pulses. In the frequency domain such trains form frequency combs. We show that driving atoms by frequency combs that do not satisfy the two-photon Raman resonance condition results in a persistent radiative force. We also propose a see-saw scheme of cooling multilevel atoms. In these scheme the teeth of the frequency comb are periodically moved in and out of resonance for the allowed transitions. The see-saw cooling may be practically attained by switching carrier-envelope phase between predefined values. We carry out numerical calculations of optimal train parameters, radiative force and time evolution of the velocity distribution

\textsuperscript{1}This work was supported in part by the ARO.

3:36PM J2.00009 Towards site-resolved imaging and control of ultracold fermions in optical lattices, FLORIAN HUBER, WIDAGDO SETIAWAN, KATE WOOLEY-BROWN, MAXWELL PARSONS, SEBASTIAN BLATT, MARKUS GREINER, Harvard University — Recent successes in site-resolved imaging and control of bosonic Rb atoms trapped in optical lattices have enable many new possibilities to emulate simple condensed matter systems. Many of the open questions in condensed matter, however, stem from the fermionic nature of electrons. Extending the high degree of control available with ultracold quantum gases in optical lattices to fermionic atoms will allow us to address these questions. The light mass of fermionic 6-Li leads to system dynamics on fast timescales, making it an ideal candidate for such studies. We report progress towards a 6-Li quantum gas microscope and present improved imaging, cooling, and trapping techniques compatible with the light mass of 6-Li. A major challenge in the pursuit of single-site imaging with Lithium is cooling during the imaging process. Single-site experiments with bosons benefit from the resolved hyperfine splitting in the excited state of 87-Rb, which allows the use of optical molasses. This method cannot be straightforwardly applied to 6-Li. We present our efforts to cool and image 6-Li using Raman sideband cooling.

3:48PM J2.00010 Optical control of Feshbach resonances in Fermi gases using molecular dark states, HAIBIN WU, Department of Physics, Duke University, Durham, NC 27708, USA, JOHN E. THOMAS, Department of Physics, North Carolina State University, Raleigh, NC 27695, USA — We investigate optical control of magnetic Feshbach resonances in ultracold atomic gases with more than one molecular state in an energetically closed channel. Using two optical fields to couple two states in the closed channel, inelastic collisional loss arising from spontaneous emission is greatly suppressed by destructive quantum interference near the two-photon resonance, i.e., dark-state formation, while the scattering length is widely tunable. Further, the effective range can be controlled by varying the parameters of optical fields. The method opens many new fields of study, such as nonequilibrium strongly interacting Fermi gases and new cooling mechanisms with narrow Feshbach resonance.

Wednesday, June 6, 2012 2:00PM - 4:00PM – Session J3 Invited Session: Gaseous Electronics Grand Ballroom E - Chair: Michael Brunger, Flinders University
2:00PM J3.00001 Differential cross sections for ionization and excitation of laser-aligned atoms by electron impact, ANDREW MURRAY, University of Manchester, UK — Differential cross section measurements will be presented for electron impact ionization and excitation of atoms prepared using high resolution continuous wave laser radiation. In the case of ionization, low energy coplanar asymmetric (e,e2) experiments were performed from laser excited Mg atoms that were aligned using radiation around 285nm. The atoms were subjected to linearly polarized radiation whose polarization vector was varied from the plane to perpendicular to the scattering plane. Ionization measurements were then conducted from the laser-excited 3P state, and the differential cross section determined. By careful analysis of the laser pumping, these measurements were directly compared to those from the ground state. Such experiments provide valuable information on the ionization of aligned targets. In the second experiment to be described here, a resonant enhancement cavity has been placed around the interaction region and super-elastic scattering measurements have been carried out from laser-excited atoms inside the cavity. This new technique opens up many new targets for study, since the cavity increases the effective intensity of the laser radiation that is exciting the atoms by a factor of up to 50. As such, new ionization and excitation measurements are possible using deep UV radiation where the laser power is only a few mW. Results from calcium will be presented, and progress towards studies from silver, copper and gold will be discussed. We are also advancing this new technique to allow simultaneous excitation from the hyperfine levels of different targets (such as Rb), which will allow the method to be adopted in different fields, such as laser cooling and trapping.

2:30PM J3.00002 Two dimensional laser-collision induced fluorescence measurements in low pressure plasmas, ED BARNAT, Sandia National Laboratories — Diagnostic techniques that enable the measurement of the temporal and spatial evolution of a plasma discharge provide insight into the mechanisms governing the behavior of a plasma discharge. In this presentation, the development and implementation of a two-dimensional laser diagnostic known as laser-collision induced fluorescence (2D-LCIF) is described. The technique relates the redistribution of laser excited population into nearby states to the density and electron energy via a collisional-radiative model (CRM) also described in this work. Central to the successful implementation of this technique is proper knowledge of the energy dependence of electron impact excitation between the various levels of the atomic or molecular system probed. Emphasis is placed on the ability of the technique to provide two dimensional maps of the electron densities in a plasma discharge. Discussion is also offered on the techniques ability to characterize the “effective temperature” of the electrons by observing relative changes in the excitation rates across a plasma discharge. Application of the 2D-LCIF technique to structurally interesting plasmas is demonstrated. While earlier studies have focused on helium, effort is underway to extend the technique to other systems such as argon. This work was supported by the Department of Energy Office of Fusion Energy Science Contract DE-SC0001939

3:00PM J3.00003 Transport and collisional processes for electrons in gases and their application to study non-equilibrium plasmas, SASA DUJKO, Institute of Physics, University of Belgrade, PO Box 68, Zemun 11080, Belgrade, Serbia — As atomic and molecular collisions critically shape distributions and rates in low temperature plasmas the advancements in modern day technology associated with the non-equilibrium plasma discharges are critically dependent on accurate modeling of the underlying collision and transport processes for charged particles in gases. To meet these challenges, we have undertaken a program to understand the kinetic behavior of charged particles under the combined action of electric and magnetic fields in neutral gases. A multi term theory for solving the Boltzmann equation has been developed and used to calculate transport coefficients of charged-particle swarms in neutral gases. In this talk, I will focus on non-equilibrium magnetized plasma discharges where the electric and magnetic fields can vary in space, time and orientation depending on the type of discharge and where attention must be paid to the correct treatment of temporal and spatial non-locality within the discharge. In particular, I will highlight the duality of transport coefficients arising from the explicit effects of non-conservative processes. As an example of fluid modeling, I will discuss the recently developed high order fluid model for streamer discharges. Starting from the cross sections for electron scattering, it will be shown how the corresponding transport data required as input in fluid model should be calculated under conditions when the local field approximation is not applicable. Comparison between the temporal evolution of electron number density and electric field from the classical first order and that from high order model are made and differences will be addressed using physical arguments.

3:30PM J3.00004 Benchmark Calculations of Atomic Data for Modelling Applications, KLAUS BARTSCHAT, Drake University — In recent years, much progress has been achieved in calculating reliable cross-section datasets for electron scattering from atoms and ions, in particular quasi-one and quasi-two electron systems such as H, He, the alkalies, and the alkaline-earth metals. Until recently, however, accurate calculations of electron collisions with more complex targets, such as the heavy noble gases Ne–Xe, have remained a significant challenge to theory. In this talk, we will illustrate with a few examples how the B-spline R-matrix (BSR) method with non-orthogonal orbitals [1-3] has been able to dramatically improve the quality of theoretical datasets for oscillator strengths [4] as well as electron collisions with numerous targets, including the heavy noble gases [5], and how these data were used successfully in modelling applications [6]. The most recent extension of the method, the B-spline R-matrix with Pseudo-States (BSRMPMS) approach, includes a large number of pseudostates in the close-coupling expansion, thereby allowing for the fully non-perturbative treatment of highly correlated processes such as ionization and even ionization with simultaneous excitation [7].

Wednesday, June 6, 2012 2:00PM - 4:00PM — Session J4 Photoionization or Photofragmentation of Homonuclear Molecules Garden 1-2 - Chair: Wendell Hill, National Science Foundation

2:00PM J4.00001 A direct measurement of the dissociative lifetimes for Superexcited States of Molecular Oxygen, HENRY TIMMERS, NIRANJAN SHIVARAM, ARVINDER SANDHU, The University of Arizona — Using an atomscend extreme ultraviolet (XUV) pump-probe setup, we performed a direct measurement of the dissociation lifetime of superexcited states corresponding to the n\(\ell\)\(\nu\)\(g_u\)(\(C_u^\pm\)) Rydberg series of \(O_2\). Superexcited states are highly-excited, neutral molecular states which lie far above the first ionization potential. These states are found to play a major role in the chemistry of the upper atmosphere but are difficult to model due to their non-Born-Oppenheimer behavior. Using a direct time-domain scheme, we measured a dissociation lifetime of \(\tau_g = 105 \pm 8 \) fs, a factor 1.5 longer than dissociation lifetimes reported for the molecular ion-core. These results indicate the influence of the Rydberg electron on the ultrafast fragmentation dynamics of the ion-core and can provide insight into interaction between electronic and nuclear degrees of freedom in the non-Born-Oppenheimer regime.

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1 This work has been done in cooperation with Dr Zoran Petrovic, Dr Ron White and Dr Ute Eberth.

2 This work was performed in collaboration with Oleg Zatsarinny. It is supported by the United States National Science Foundation under PHY-0903818 and PHY-1068140, and by the TeraGrid/XSEDE allocation TG-PHY090031.
2:12PM J4.00002 Ultrafast Dynamics of Ozone Exposed to Ionizing Radiation, CRAIG HOGLE, University of Colorado - JILA, PREDRAG RANITOVIC, Lawrence Berkeley National Laboratory, WILLIAM PETERS, AUSTIN SPENCER, University of Colorado - Chemistry, LEIGH MARTIN, University of Colorado - JILA, DAVID JONAS, University of Colorado - Chemistry, XIAO-MIN TONG, University of Tsukuba, Japan, MARGARET MURNANE, HENRY KAPTEYN, University of Colorado - JILA — By irradiating ozone molecules with few-femtosecond soft x-ray pulses and probing the fragmentation pathways, we find that any excess energy is rapidly and efficiently transferred into internal excitation of the triatomic molecule. We explore the Coulomb explosion of O$_3$, when irradiated with soft x-rays above the double ionization threshold, at photon energies in the XUV (43 eV) range. The super-excited states are then probed using a femtosecond infrared (IR) pulse in combination with 3D coincidence momentum imaging (COLTRIMS). By comparing the O$_3^+$ and O$_3^-$ ion fragmentation yields as a function of time delay between the XUV pump and IR probe, we find that the triatomic ozone molecule shows an ability to absorb any excess energy internally rather than emerging as kinetic energy released by the Coulomb exploding fragments. This internal conversion of energy in a triatomic molecule before explosion is very different from the case of diatomic molecular oxygen.

2:24PM J4.00003 Two are better than one: Combining ATI and KER spectra, C.B. MADSEN, B.D. ESRY, J.R. Macdonald Laboratory, Department of Physics, Kansas State University — Molecular breakup in a strong laser field is a vital topic, because measurement of the resulting fragments is a key tool for learning about their dynamics. Studies of kinetic energy release (KER) and above-threshold-ionization (ATI) spectra as a function of, e.g., molecular alignment and carrier-envelope-phase have revealed important information about both nuclear and electronic behavior. We explore the potential of gaining even more insight by investigating the breakup probability as a function of all fragment energies at once. As ATI and KER spectra are projections of the joint energy spectrum, this joint spectrum gives a more detailed look into fragmentation dynamics. Validating our strong-field-approximation-based qualitative picture for H$_2^+$ allows us to generalize our studies to larger molecules. In particular, we show that when the fragmentation probability of even a complex molecule is resolved onto the energies of all fragments, the probability peaks on surfaces separated by the photon energy where the distribution on a given multi-photon surface reflects structure and dynamics of the molecule.

3:06PM J4.00004 R-dependent strong field ionization from a neutral ground state diatomic molecule, GEORGE GIBSON, VINCENT TAGLIAMONTI, HUI CHEN, University of Connecticut — Strong-field ionization of molecules is significantly more complicated than for atoms, due to the rotational and vibrational degrees of freedom and the closer energy spacing of different orbitals. However, a complete understanding of strong field ionization may lead to new techniques for understanding the electronic structure of molecules. Especially interesting would be a way to probe how the orbital structure changes as a function of internuclear separation. To this end, we have begun a series of experiments on I$_2$ molecules in which we create a coherent vibrational wavepacket centered on $v=33$ of the ground state of the neutral molecule. This allows us to probe ionization as a function of internuclear separation in the neutral ground state, for the first time.

4:00PM J4.00005 Effect of moving nuclei in multiphoton ionization of the H$_2^+$ ion, XIAOXU GUAN, KLAUS BATRCHAT, Drake University, BARRY I. SCHNEIDER, National Science Foundation — We propose an accurate $ab$ initio numerical method to depict the dynamics of the nuclear fragments and the entangled motion of the nuclei and the electron in the laser-driven H$_2^+$ ion. Building on recent work [1], we solve the time-dependent Schrödinger equation in prolate spheroidal coordinates and extract the angle-differential cross section for the photoelectron as a function of internuclear separation in the neutral ground state, for the first time.

4:12PM J4.00006 Femtosecond XUV Transient Absorption of Strong-Field Induced Vibrational Wavepackets in Molecular Bromine, ERIK HOSLER, STEPHEN LEONE, University of California, Berkeley — The development of table-top extreme ultraviolet (XUV) transient absorption spectroscopy has allowed for the investigation of chemical dynamics with both elemental specificity and chemical environment sensitivity on the femtosecond and even attosecond timescales in real-time. In this experiment, vibrational wavepackets in molecular bromine are simultaneously prepared by high field ionization on the neutral and ionized ground state potentials via an 800 nm (2.0 x 10$^4$ W/cm$^2$) pump. High harmonic generation from a semi-infinite gas cell source is then employed to probe the wavepacket evolutions via the core level transient absorption signal amplitude, with 105 fs and 92 fs periods, respectively, which are indicative of the creation of vibrational coherences in both states. The subsequent dissociative ionization of atomic bromine is also observed through the Br$^+$ 2P$_{3/2}$-$^2$D$_{5/2}$, 2P$_{1/2}$-$^2$D$_{3/2}$, 2P$_{3/2}$-$^2$D$_{1/2}$, and 2P$_{3/2}$-$^2$D$_{3/2}$ transitions. Probing of the vibrational coherences via core level excitation allows for state selective investigation of the strong-field ionization dynamics from an elemental perspective. Extension of this work to polynomials should allow for site and state selective investigation of both vibrational and electronic coherences.

5:00PM J4.00007 Angle-resolved and internuclear-separation-resolved measurements of the ionization rate of the B state of I$_2$ by strong laser fields, HUI CHEN, University of Connecticut, LI FANG, Western Michigan University, VINCENT TAGLIAMONTI, GEORGE GIBSON, University of Connecticut, GIBSON TEAM — For the first time, angle and internuclear separation resolved measurements of the single ionization rate of neutral I$_2$ have been obtained. By launching a wavepacket in the B$^3Π_u^+$ (B-state) of I$_2$ with a 50 fs tunable pump pulse we can measure the ionization rate as a function of internuclear separation as the wavepacket evolves in the B-state. Moreover, since the ground to B-state optical transition dipole moment is parallel to the internuclear axis, the B-state sub-population of the I$_2$ thermal ensemble will have a high degree of alignment, allowing for angular measurements. The B-state shows the well-known effect of enhanced ionization at a critical separation $R_c$ with an enhancement factor of 22 when the ionizing field is polarized along the internuclear axis and the enhanced ionization decreases when the angle between the field and the axis decreases from 0° to 90°, finally disappearing at 90°. These results on the enhanced ionization of the B-state of I$_2$ give the most precise determination of $R_c$ for any molecule and agree extremely well with the prediction from a simple model of electron localization.

3 We would like to acknowledge support from the NSF under Grant No. PHYS-0968799.

1 Supported by Kansas State University and by the Chemical Sciences, Geosciences, and Biosciences Division, Office of Basic Energy Sciences, Office of Science, U.S. Department of Energy.

1 We would like to acknowledge support from the NSF under Grant No. PHYS-0968799.
3:24PM J4.00008 Routes to formation of highly excited neutral atoms in the break-up of strongly driven hydrogen molecule

AGAPI EMMANOUILIDOU, University College London — We present a theoretical quasiclassical treatment of the formation, during Coulomb explosion, of highly excited neutral H atoms for strongly-driven hydrogen molecule. This process, where after the laser field is turned off, one electron escapes to the continuum while the other occupies a Rydberg state, was recently reported in an experimental study in Phys. Rev. Lett. 102, 113002 (2009). We find that two-electron effects are important in order to correctly account for all pathways leading to highly excited neutral hydrogen formation [1]. We identify two pathways where the electron that escapes to the continuum does so either very quickly or after remaining bound for a few periods of the laser field. These two pathways of highly excited neutral H formation have distinct traces in the probability distribution of the escaping electron momentum components.


3:36PM J4.00009 Double ionization of dimers in intense laser pulses

HONGCHENG NI, JILA, University of Colorado at Boulder, USA, CAMILO RUIZ, Centro de Láseres Pulsados Ultracortos Ultrainintensos, Spain, ANDREAS BECKER, JILA, University of Colorado at Boulder, USA — Experiments on double ionization of rare gas dimers by weak synchrotron radiation as well as by strong infrared laser pulses have been reported recently. New pathways to double ionization, in which the electrons are emitted either from the same atom or different atoms in the dimer, have been proposed on the basis of the experimental data. We apply a recently developed theoretical two-electron model to explore the correlated emission of two electrons in a rare gas dimer due to the interaction with attosecond VUV and XUV radiation and/or intense near-infrared laser pulses. In particular, we study the double ionization mechanisms mediated by electron correlation and their temporal resolution.

Wednesday, June 6, 2012 2:00PM - 4:00PM –
Session J5 DAMOP Thesis Prize Session
Garden 3

2:00PM J5.00001 Quantum gas microscopy: an atomic scale probe of strongly-correlated many-body systems

WASEEM BAKR, Massachusetts Institute of Technology — Ultracold atomic systems can be used to simulate a range of phenomena in strongly-correlated materials ranging from high-Tc superconductors to quantum magnets. The micron-scale spacing of atoms in these systems provides an opportunity to optimally image fluctuations and correlations in strongly correlated systems in a way not possible in condensed matter. In this talk, I will present new insight from spatially-resolved, in situ images of ultracold atoms confined in a two-dimensional (2D) trap, with a focus on critical regions of continuous phase transitions. In situ imaging of a monolayer of 2D gas reveals precise atomic density distributions, providing advantages in studying equilibrium thermodynamics, transport properties, as well as density fluctuations and spatial correlations away from thermal equilibrium, many of which are difficult to resolve in conventional bulk measurements. Using samples prepared at various temperatures and atomic interaction strengths, we confirm scale invariance and universality of weakly interacting 2D gases near the Berezinskii-Kosterlitz-Thouless transition, and verify the theory describing its critical behavior. Density-density correlations and static structure factors are also extracted, revealing intriguing quantum behavior of underlying many-body phases. By loading a 2D gas into a square lattice potential, we induce the superfluid-Mott insulator quantum phase transition, and observe the quantum phase transition between antiferromagnetic and paramagnetic phases. QGM also allowed us to observe orbital excitation blockade, providing advantages in studying equilibrium thermodynamics, transport properties, as well as density fluctuations and spatial correlations away from thermal equilibrium. In this talk, I will present new insight from spatially-resolved, in situ images of ultracold atoms confined in a two-dimensional (2D) trap, with a focus on critical regions of continuous phase transitions.

2:30PM J5.00002 In situ probing of two-dimensional quantum gases

CHEN-LUNG HUNG, California Institute of Technology — Experiments on ultracold gases offer unique perspectives to unveil many-body phenomena near phase transitions described by paradigmatic condensed matter models. In this talk, I will present new insight from spatially-resolved, in situ images of ultracold atoms confined in a two-dimensional (2D) trap, with a focus on critical regions of continuous phase transitions. In situ imaging of a monolayer of 2D gas reveals precise atomic density distributions, providing advantages in studying equilibrium thermodynamics, transport properties, as well as density fluctuations and spatial correlations away from thermal equilibrium, many of which are difficult to resolve in conventional bulk measurements. Using samples prepared at various temperatures and atomic interaction strengths, we confirm scale invariance and universality of weakly interacting 2D gases near the Berezinskii-Kosterlitz-Thouless transition, and verify the theory describing its critical behavior. Density-density correlations and static structure factors are also extracted, revealing intriguing quantum behavior of underlying many-body phases. By loading a 2D gas into a square lattice potential, we induce the superfluid-Mott insulator quantum phase transition, and observe the phase transition between antiferromagnetic and paramagnetic phases. QGM also allowed us to observe orbital excitation blockade, providing advantages in studying equilibrium thermodynamics, transport properties, as well as density fluctuations and spatial correlations away from thermal equilibrium.

1This work was performed at the University of Chicago under the supervision of Prof. Cheng Chin.

3:00PM J5.00003 Cavity-Enabled Spin Squeezing for a Quantum-Enhanced Atomic Clock

MONIKA SCHLEIER-SMITH, Max Planck Institute of Quantum Optics and LMU Munich — For the past decade, the stability of microwave atomic clocks has stood at the standard quantum limit, set by the projection noise inherent in measurements on ensembles of uncorrelated particles. We have now, in proof of principle, surpassed this limit by operating with atoms in a particular type of entangled state called a “squeezed spin state.” The generation of non-classical spin correlations in a dilute cloud of atoms is facilitated by an optical cavity, which allows for strong collective coupling of the atomic ensemble to a single mode of light. Since the light exiting the cavity is entangled with the atoms, an appropriate measurement performed on the light field can project the atomic ensemble into a squeezed spin state. We have demonstrated 3.0(8) dB of spin squeezing by this method of quantum non-demolition measurement. We have further developed a new method, cavity feedback squeezing, which uses the light field circulating in the resonator to mediate an effective interaction among the atoms. The states prepared by cavity feedback are intrinsically squeezed by up to 10(1) dB and detectably squeezed by up to 5.6(6) dB. Applied in an atomic clock, they produce an Allan variance 4.7(5) dB below the standard quantum limit for averaging times of up to 50 s.

3:30PM J5.00004 Molecular interactions in and with fields: thermal collisions, ultracold gases, supersymmetry1. MIKHAIL LEMESHKO, ITAMP, Harvard-Smithsonian Center for Astrophysics and Harvard Physics Department, Cambridge, Massachusetts 02138, USA — The work to be presented in this talk is chiefly concerned with developing new techniques to manipulate molecular states and interactions by means of static and radiative fields. The talk will describe a simple analytic model to rationalize molecular collisions, both field-free and in fields; techniques to fine-tune and probe weakly-bound molecular states and to enhance the photoassociation rate of ultracold atoms with far-off-resonant light; the use of supersymmetric quantum mechanics to find exact solutions to the eigenproblem of molecules subject to a particular combination of fields; new types of intermolecular potentials shaped by far-off-resonant light. Of relevance to ongoing experiments, this work offers insights into few-body AMO physics and may induce the study of many-body effects it anticipates in the collective behavior of ultracold gases.

1This work was performed at the Fritz Haber Institute of the Max Planck Society (Berlin, Germany), under the supervision of Prof. Dr. Bretislav Friedrich.

Wednesday, June 6, 2012 2:00PM - 4:00PM – Session J6 Atomic Clocks and Magnetometers Garden 4 - Chair: Chris Oates, NIST

2:00PM J6.00001 $^{87}$Sr Clock Comparisons at JILA. JASON WILLIAMS, TRAVIS NICHOLSON, BENJAMIN BLOOM, SARA CAMPBELL, MICHAEL MARTIN, MATTHEW SWALLows, MICHAEL BISHeF, JUH YE, JILA, NIST, and the University of Colorado — Great advances are being realized with optical lattice clocks, where spectroscopy at optical frequencies and large ensembles of neutral atoms combine to offer extremely high frequency precision and stability. Recent results from the Strontium $87$ optical atomic clock at JILA have demonstrated that strong interactions among fermions confined in a two-dimensional (2D) optical lattice suppress the collisional frequency shift and its uncertainty to the level of $10^{-17}$ [1]. We report on the progress of a second optical lattice clock at JILA, in which fermionic $^{87}$Sr atoms are confined in a lattice potential derived from optical buildup cavities to provide strong confinement over a very large volume in one, two, and three dimensional lattices. Intercomparisons of the two clocks at JILA will be used to explore in greater detail the physics governing the transition shifts and uncertainties in our two $^{87}$Sr optical lattice systems and will provide a significant improvement of our systematic errors.


2:12PM J6.00002 S-Wave Clock Shift for Fermions. E.L. HAZLETT, Y. ZHANG, R.W. STITES, K. GIBBLE, K.M. O’HARA, The Pennsylvania State University — Optical lattice clocks use ultracold fermionic atoms to minimize density-dependent frequency shifts since s-wave scattering of identical fermions is forbidden. Indeed, frequency shifts are absent in a Fermi gas if a spatially homogeneous clock field interrogates the atoms. However, any spatial inhomogeneity in the clock field produces distinguishable fermions and density-dependent frequency shifts. This is directly pertinent for optical lattice clocks since inhomogeneities are naturally larger for optical frequency fields (in comparison to microwave or radio-frequency fields). We study collisional frequency shifts in a Fermi gas for which we control and characterize both the interactions and the spatial inhomogeneity of the clock field. The frequency shifts we observe exhibit novel density dependencies that are different from the mean-field shifts of homogeneously excited bosons. Our description provides a physical picture of the origin of the frequency shift and indicates the experimental parameters that must be controlled to eliminate density-dependent clock shifts.

2:24PM J6.00003 High accuracy measurement of optical atomic clock polarizability. JEFF SHERMAN, National Institute of Standards and Technology, NATHAN LEMKE, NATHAN HINKLEY, University of Colorado, Department of Physics, MARCO PIZZOCARO, Politecnico di Torino, Italy, RICHARD FOX, ANDREW LUDLOW, CHRIS OATES, National Institute of Standards and Technology — The differential static polarizability of ytterbium optical clock states $\alpha_{\text{clock}} \equiv \alpha'(P) - \alpha'(S)$ is known theoretically to $\sim 10\%$. We report an experimental value of this polarizability, $\alpha_{\text{clock}} = 36.2612(7) \times 10^{-30} \text{cm}^3 / \text{V}^2$ at 20 parts-per-million (ppm) accuracy [1]. Ultracold $^{171}$Yb atoms held in an optical lattice at the ac-Stark balancing “magic” wavelength (759 nm) are surrounded by rigidly spaced transparent conductive planar electrodes. An ultrastable laser (578 nm) is locked to the $^{2}S_{0} \rightarrow ^{2}P_{1}$ transition in an interleaved fashion for three electrode conditions: voltage applied, reversed, and grounded. These integrated error signals yield the quadratic Stark shift and a measure of stray fields. The electrode spacing is measured interferometrically $\delta 21$ [K. Gibble et al., Science, 331, 1043 (2011)].


2:36PM J6.00004 Anomalously small BBR shift in $^{171}$Tl+ frequency standard. Z. ZUHRiadha, MARIANNa SAFrONOVA, University of Delaware, MIKHAIL KOZLOV, Petersburg Nuclear Physics Institute — The operation of atomic clocks is generally carried out at room temperature, whereas the definition of the second refers to the clock transition in an atom at absolute zero. This implies that the clock transition frequency should be corrected in practice for the effect of finite temperature of which the leading contributor is the blackbody radiation (BBR) shift. In the present work, we have used configuration interaction + coupled-cluster method to evaluate polarizabilities of the $6s \rightarrow ^{2}S_{0}$ and $6s6p \rightarrow ^{2}P_{1}$ states of $^{171}$Tl; $\alpha(1S_{0}) = 19.5$ a.u. and $\alpha(2P_{1}) = 21.4$ a.u. We find dynamic correction to the BBR shift to be negligible. The resulting BBR shift at $300$ K is $\Delta_{\text{BBR}} = -0.0160(17)$ Hz. This result demonstrates that near cancelation of the $^2S_{0}$ and $^2P_{1}$ state polarizabilities in monovalent $^{171}$Tl, $^{171}$Al. $^{171}$In $^{15}$ ions of group 13 [Safonova et al., PRL 107, 143006 (2011)] continues for much heavier $^{171}$Tl, leading to anomalously small BBR shift for this system. The corresponding relative BBR shift at $300$ K is $\Delta_{\text{BBR}}/\nu_0 = 1.1(1) \times 10^{-17}$. This calculation demonstrates that the BBR contribution to the fractional frequency uncertainty of the $^{171}$Tl+ frequency standard at $300$ K is $1 \times 10^{-18}$.

1 NSF and RFBR

2:48PM J6.00005 Developing a Portable Optical Frequency Standard with Atomic Mercury. KAITLIN MOORE, EMILY ALDEN, AARON LEANHARDT, University of Michigan — A two-photon excitation strategy is proposed to couple the $^1S_0$ and $^3P_0$ levels of mercury atoms with zero nuclear spin and in the presence of zero external magnetic field. This excitation strategy could allow for a portable optical frequency standard based on a thermal mercury vapor with a fractional frequency resolution at the $\sim 10^{-15}$ level. The $^1S_0 \rightarrow ^3P_0$ transition requires two photons at 531 nm, which are generated by a compact solid state laser system. Detection of population in the $^3P_0$ state with ground state ammonia molecules.

1 NSF and RFBR
3:00PM J6.00006 Referencing an Oscillator to the Rest Mass of an Atom. MICHAEL HOHENSEE, SHAU-YU LAN, BRIAN ESTEY, PEI-CHEN KUAN, DAMON ENGLISH, PAULI KEHAYIAS, HOLGER MÜLLER, Physics Department, University of California, Berkeley — Modern atomic frequency standards are referenced to transitions between two different internal electronic states of an atom, or trapped ion. The superior fractional stability demonstrated by trapped ion clocks over previous frequency standards stems from the fact that ion clocks are referenced to an optical (∼10^{14} Hz), rather than a microwave (∼10^{10} Hz) transition, while the underlying systematic shifts of the ion’s energy levels are controlled at comparable levels in both systems. Still higher oscillation frequencies (∼10^{20} Hz) are exhibited by the Compton-frequency (∝m_{e}c^2/h) phase oscillations of a massive particle’s wave function, but such frequencies are too fast to access directly. In this talk, we will describe the physics of how matter-wave interferometers can indirectly access these Compton-frequency oscillations, and be used to lock a real world RF oscillator to a specific subharmonic of νC.

3:12PM J6.00007 Progress toward a search for spin-mass couplings of the proton 1. JULIAN VALDEZ, JERLYN SWIATLOWSKI, CESAR RIOS, CAITLIN MONTCREIFFE, DEREK JACKSON KIMBALL, California State University - East Bay — We report progress in our experiment to use a dual-isotope rubidium magnetometer to search for a long-range coupling between proton spins and the mass of the Earth. The valence electron dominates magnetic interactions and serves as a precise co-magnetometer for the nuclei in a simultaneous measurement of Rb-85 and Rb-87 spin precession frequencies, enabling accurate subtraction of magnetic perturbations. Both Rb nuclei have valence protons, but in Rb-85 the proton spin is parallel to the nuclear spin and magnetic moment while for Rb-85 the proton spin is anti-parallel to the nuclear spin and magnetic moment. Thus anomalous interactions of the proton spin produce a different shift between the Rb spin-precession frequencies, whereas many sources of systematic error produce common-mode shifts of the spin-precession frequencies which can be controlled through auxiliary measurements. We discuss optimization of the magnetometer sensitivity, methods to control systematic effects due to light shifts, collisions, and the gyro-compass effect, and preliminary data.

3:24PM J6.00008 Liquid-state nuclear spin comagnetometers 1. MICHAEL LEDBETTER, SYZMONE PUSTELNY, DIMITRY BUDKER, U.C. Berkeley, MICHAEL ROMALIS, Princeton University, JOHN BLANCHARD, ALEXANDER PINES, U.C. Berkeley — We discuss liquid-state nuclear spin comagnetometers based on mixtures of mutually miscible solvents, each rich in a different nuclear spin. In one version thereof, thermally polarized 1H and 129Xe nuclear spins in a mixture of pentane and hexafluorobenzene are monitored in 1 mg fields using alkali-vapor magnetometers. In a second version, 1H and 129Xe nuclei in a mixture of pentane and hyperpolarized liquid xenon are monitored with a superconducting quantum interference device. In the former case, we show that magnetic field fluctuations can be suppressed by a factor of about 3400 and that frequency resolution of about 5 × 10^{-11} Hz may be realized in roughly one day of integration. We discuss the application of liquid-state nuclear spin comagnetometers to precision measurements such as a search for spin-gravity coupling or a permanent electric dipole moment, as well as to sensitive gyroscopes.

3:36PM J6.00009 Precision Magnetometry with Spin-Polarized Xenon. SKYLER Degenkolb, AARON LEANHARDT, TIM CHUPP, University of Michigan — Atomic magnetometer sensitivity is a limiting factor in precision measurements, medical imaging, and industrial applications. In particular, searches for permanent electric dipole moments (EDMs) require sensitive magnetometers which interact minimally with the primary samples. Techniques based on spin-polarized gases have been very successful in this capacity, but it remains difficult to perform correct spatial and temporal averages. Previous magnetometers (e.g., alkalis or 199Hg) also suffer from material problems at the high voltages and low temperatures common in EDM experiments. We propose as a remedy real-time optical magnetometry based on spectroscopy of two-photon transitions in spin-polarized 129Xe. Thermal, diffusive, and dielectric properties of xenon allow sensitive measurements in a wide range of electromagnetic field strengths and sample volumes, while long spin coherence times and a low neutron capture cross-section are favorable in neutron EDM experiments. We report on preliminary work validating the technique in 171Yb and a parallel effort measuring the 129Xe EDM, and discuss applications to contemporary neutron EDM measurements.

3:48PM J6.00010 Precision magnetometry using NV centers in diamond. DAVID LE SAGE, Harvard-Smithsonian Center for Astrophysics, LINH MY PHAM, NIR BAR-GILL, Harvard University, CHINMAY BELTHANGADY, Harvard-Smithsonian Center for Astrophysics, KEIGO ARAI, Massachusetts Institute of Technology, RONALD WALSWORTH, Harvard-Smithsonian Center for Astrophysics — The nitrogen-vacancy (NV) color center in diamond promises to be an extremely useful tool for precise optical magnetometry. Individual NV centers can function as atomic-scale magnetometers, for high spatial-resolution measurements, with close proximity between the field source and sensor. Improved sensitivities may be realized in roughly one day of integration. We discuss the application of liquid-state nuclear spin comagnetometers to precision measurements such as a search for spin-gravity coupling or a permanent electric dipole moment, as well as to sensitive gyroscopes.

Wednesday, June 6, 2012 2:00PM - 4:00PM –
Session J7 Quantum Computing II Terrace - Chair: Patricia Lee, Army Research Laboratory

2:00PM J7.00001 Entanglement of ions in a uniformly-spaced chain using individual addressing and pulse shaping1. S. DEBNATH, T.A. MANNING, T. CHOI, B. FIELDS, C. MONROE, JQI and Department of Physics, University of Maryland, College Park, MD 20742 — We present progress towards entanglement of subsets of 171Yb+ ions in a single uniformly-spaced chain using individual optical addressing and simple laser pulse shaping. A pulsed 355 nm laser drives Raman transitions to create a spin-dependent force on individual ions in the chain, where the collective ion motion facilitates the entanglement of the ions’ spin states. By coupling to transverse phonon modes instead of axial modes, we will be less sensitive to thermal motion and ion heating, resulting in comparatively higher gate fidelities. Additionally, faster gate speeds are achievable by applying sequences of a few laser pulses at optimized intensities and detuning that couple to multiple modes of motion [1,2].


1This work is supported by grants from the U.S. Army Research Office with funding from the DARPA OLE program, IARPA, and the MURI program; the NSF PIF Program; the NSF Physics Frontier Center at JQI; and the European Commission AQUTE program.
2:12PM J7.00002 Quantum Information Processing with Ytterbium Ions and a Frequency Comb in a Surface Trap\textsuperscript{1}, EMILY MOUNT, SO-YOUNG BAEK, DANIEL GAULTNEY, STEPHEN CRAIN, RACHEL NOEK, PETER MAUNZ, JUNGSANG KIM, Fitzpatrick Institute for Photonics, Electrical and Computer Engineering Department, Duke University — Microfabricated surface ion traps are one of the key components for building a trapped ion quantum information processor. These multi-segmented traps are fabricated using existing silicon processing technology and can provide the fields to store a chain of ions and shuttle ions within the trap structure. Using a surface trap microfabricated by Sandia National Laboratories \cite{1} we trap individual Yb-171 ions and demonstrate fundamental quantum information processing primitives. Low light scatter from the trap and the use of photon arrival times during fluorescence state detection enables a state detection fidelity of 98\%. High fidelity rotations of the hyperfine clock state qubit have been performed using a resonant microwave field. Furthermore, we have realized single qubit rotations using Raman transitions driven by a repetition-rate stabilized frequency comb, a prerequisite for realizing motional gates with frequency combs \cite{2}. Microelectromechanical systems (MEMS) mirrors will be used to focus Raman laser beams on individual ions in a chain to perform single qubit gates. MEMS beam steering systems can easily be scaled to multiple beams to realize two-ion gates between arbitrary ions in the chain.  
\textsuperscript{1}D Stick et al., arXiv:1008.0990v2 2010
\textsuperscript{2}D Hayes et al., PRL 104(14)2010

3This work was supported by IARPA/ARO.

2:24PM J7.00003 ABSTRACT WITHDRAWN —

2:36PM J7.00004 ABSTRACT WITHDRAWN —

2:48PM J7.00005 Adiabatic Quantum Computing with Neutral Atoms\textsuperscript{1}, AARON HANKIN, University of New Mexico, GRANT BIEDERMANN, GEORGE BURNS, YUAN-YU JAU, CORT JOHNSON, SHANALYN KEMME, ANDREW LANDAHL, MICHAEL MANGAN, L. PAUL PARAZZOLI, PETER SCHWINDT, DARRELL ARMSTRONG, Sandia National Laboratories, IVAN DEUTSCH TEAM\textsuperscript{2}, MARK S AffMAN TEAM\textsuperscript{3} — We are developing, both theoretically and experimentally, a neutral atom qubit approach to adiabatic quantum computation. Using our microfabricated diffractive optical elements, we plan to implement an array of optical traps for cesium atoms and use Rydberg-dressed ground states to provide a controlled atom-atom interaction. We will develop this experimental capability to generate a two-qubit adiabatic evolution aimed specifically toward demonstrating the two-qubit quadratic unconstrained binary optimization (QUBO) routine.

\textsuperscript{1}Work funded by Laboratory Directed Research and Development
\textsuperscript{2}University of New Mexico
\textsuperscript{3}University of Wisconsin

3:00PM J7.00006 Adiabatic Quantum Computing via the Rydberg Blockade , TYLER KEATING, KRITTIKA GOYAL, IVAN DEUTSCH, CQuIC, University of New Mexico — We study an architecture for implementing adiabatic quantum computation with trapped neutral atoms. Ground state atoms are dressed by laser fields in a manner conditional on the Rydberg blockade mechanism, thereby providing the requisite entangling interactions. As a benchmark we study the performance of a Quadratic Unconstrained Binary Optimization (QUBO) problem whose solution is found in the ground state spin configuration of an Ising-like model. We model a realistic architecture, including the effects of magnetic level structure, with qubits encoded into the clock states of \textsuperscript{133}Cs, effective B-fields implemented through microwaves and light shifts, and atom-atom coupling achieved by excitation to a high-lying Rydberg level. Including the fundamental effects of photon scattering we find a high fidelity for the two-qubit implementation.

Krittika Goyal previously published under the name Krittika Kanjilal

3:12PM J7.00007 State Mapping and Unitary Transformations in the Cesium Hyperfine Ground Manifold , HECTOR SOSA MARTINEZ, AARON SMITH, BRIAN ANDERSON, POUL JESSEN, University of Arizona, CARLOS RIOFRIO, IVAN DEUTSCH, University of New Mexico — Quantum systems with Hilbert space dimension greater than two (qudits) provide an alternative to qubits as carriers of quantum information, and may prove advantageous for quantum information tasks if good laboratory tools for qudit manipulation and readout can be developed. We have successfully implemented a protocol for arbitrary quantum state-to-state mapping in the 16 dimensional hyperfine ground manifold of Cesium 133 atoms using only DC, rf and microwave magnetic fields to drive the atomic evolution. Experimentally we achieve a state-to-state average mapping fidelity of better than 99\%, averaged over a sample of randomly chosen initial and target states. Current work involves designing and implementing unitary transformations. We have successfully used the GRAPE algorithm to design unitary operators that can be implemented with the same experimental framework as state mapping.

3:24PM J7.00008 Utilizing Doubly Excited States of Barium for Quantum Computation and Improved Quantum Control\textsuperscript{1}, JOHN PAPAIOANNOU, CHRIS H. GREENE, JILA — The existence of doubly excited perturbers in the alkal\textendash;earth atoms provides a rich spectrum of states with possible applications for quantum information storage. Using the framework of multichannel quantum defect theory, the bound state spectra with total angular momenta up to J=5 were calculated. Due to configuration mixing, these doubly excited perturbers can have significant Rydberg character to their wavefunctions. By tuning electric fields it is possible to induce transitions between perturbers and excited Rydberg states with higher orbital angular momenta. This not only allows the possibility of improved control in exciting to high-J Rydberg states but may also be utilized as possible qubit candidates.

\textsuperscript{1}This work was supported by NSFF

3:36PM J7.00009 Single qubit gates in a 3D array of neutral atoms\textsuperscript{1}, THEODORE A. CORCOVILOS, YANG WANG, XIAO L1, DAVID S. WEISS, The Pennsylvania State University, Dept. of Physics, JUNGSANG KIM, Applied Quantum Technologies and Duke University, Dept. of Electrical and Computer Engineering — We present an approach to quantum computing using single Cs atoms in a cubic 5-\textsuperscript{6} nm spaced 3D optical lattice. After cooling the atoms to near their vibrational ground state (76\% ground state occupancy) using projection sideband cooling, we manipulate the state of individual atoms using the AC Stark shift induced by intersecting lasers and microwave pulses that are only resonant with the shifted atom. Here we demonstrate Rabi oscillations of a single atom in the center of the array and progress towards steering the beams to address the other atoms. Rapid steering of the lasers using micromirrors allows single-atom gates of S0\textsuperscript{10} ns. This single-site addressing along with lattice polarization rotation will enable us to fill voids in the central region of the atom array by selectively moving individual atoms. Future work will couple adjacent qubits via the Rydberg blockade mechanism with expected two-qubit gate times of S0\textsuperscript{100} ns.

\textsuperscript{1}We gratefully acknowledge funding from DARPA.
\textsuperscript{2}Present address: Joint Quantum Institute, University of Maryland
VLADIMIR MALINOVSKY, SERGEY RUDIN, Army Research Laboratory, Adelphi, MD 20783 — A scheme to perform arbitrary unitary operations on a single electron-spin qubit in a quantum dot is proposed. The design is based on the geometrical phase acquired after a cyclic evolution by the qubit state. The scheme is utilizing ultrafast linearly-chirped pulses providing adiabatic excitation of the qubit states and the geometric phase is fully controlled by the relative phase between pulses. The analytic expression of the evolution operator for the electron spin in a quantum dot, which provides a clear geometrical interpretation of the qubit dynamics, is obtained. Using parameters of InGaN/GaN, GaN/AlN quantum dots we provide an estimate for the time scale of the qubit rotations and parameters of the external fields. Robustness of the proposed scheme against external noise is also discussed.

4:00PM - 4:00PM
Session K1 Poster Session II (4:00 pm - 6:00 pm) Royal Ballroom

K1.00001 ATOMIC AND MOLECULAR STRUCTURE AND PROPERTIES II —

K1.00002 Every Molecule, When Created, Will Exhibit No Motion or Linear, Vibratory and or Rotational Motion Which May Later Be Altered By External Forces: A Natural Law, STEWART BREKKE, Northeastern Illinois University (former grad student) — All bodies have no motion, or linear, vibrational and/or rotational motion. Therefore, when a molecule is created, it will exhibit some or all of these properties due to the excess energy of creation if present. The energy equation for the newly created molecule is $E = m_0c^2 + 1/2mv^2 + 1/2J^2 + 1/2k\alpha^2$, where $1/2mv^2$ is the linear kinetic energy if present, $1/2J^2$ is the rotational kinetic energy if present and $1/2k\alpha^2$ is the vibrational kinetic energy of the the molecule if present.

K1.00003 Ion-Pair States in Ungerade Molecular Hydrogen$^1$, ELIZABETH MCCORMACK, Bryn Mawr College — The results of an investigation of long-range ungerade states of molecular hydrogen are reported. Resonantly enhanced multi-photon ionization via the $E,F,1^+g$ pathway, $v = 6, I = 0, 1$ and 2 states is used to probe the energy region above the $H(1s) + H(3p)$ dissociation threshold. Both molecular and atomic ion production are detected as a function of wavelength by using a time-of-flight mass spectrometer. A series of resonances is observed with energies that agree with the predictions of a mass-scaled Rydberg formula for bound states of the $H^+H$ ion pair. Measured quantum defects, rotational dependencies, and line widths are reported. The observed spectra are compared to recent theoretical predictions for the series, which include line widths that oscillate in magnitude with energy and perturbations with several interloping resonances corresponding to vibrational states trapped inside the barriers of the 5 and 6 $1^+g$ potential-energy curves.


$^1$This work is supported by the NSF.

K1.00004 S-matrix calculations of energy levels of the lithium isoelectronic sequence$^1$, J. SAPIRSTEIN, University of Notre Dame, K.T. CHENG, Lawrence Livermore National Laboratory — A QED approach to the calculation of the spectra of the lithium isoelectronic sequence is implemented. A modified Furry representation based on the Kohn-Sham potential is used to evaluate all one- and two-photon diagrams with the exception of the two-loop Lamb shift. Three-photon diagrams are estimated with Hamiltonian methods. After incorporating recent calculations of the two-loop Lamb shift and recoil corrections a comprehensive tabulation of the 2$s$, 2$p_{1/2}$ and 2$p_{3/2}$ energy levels as well as the $2s - 2p_{1/2}$ and $2s - 2p_{3/2}$ transition energies for $Z = 10 - 100$ is presented.

$^1$The work of J.S. was supported in part by NSF Grant No. NSF-1068065. The work of K.T.C. was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

K1.00005 Relativistic Configuration Interaction Lifetimes and Transition Probabilities for W II$^1$, DONALD R. BECK, MARWA H. ABDALMONEAM, Physics Department, Michigan Technological University — Lifetimes of the lowest $13, 30, 38, 40$, and 35 levels of $J=1$, 3, 5, 7 and 9, respectively, odd parity have been computed. Comparisons with measured values indicate improved agreement as compared with the semi-empirical values. With the inclusion of the FOTOS selected$^4$ $5p-5d$ excitations, agreement between the velocity and length gauges is good. Small shifts are introduced for some nearby levels to represent the missing correlation effects, and it is shown that the sum of $1/\tau$ and Lande $g$-values are nearly conserved as calculation proceeds for such levels.

$^1$Supported by the National Science Foundation. PHY-0652844
$^3$Ibid.

K1.00006 Random and modulated noise spectroscopy in a Lambda system$^1$, PENGXIONG LI, LEI FENG, Fudan University, LIANG JIANG, California Institute of Technology, YANHONG XIAO, Fudan University — Lasers have inherent phase noise, which can be converted to amplitude noise after atom-light interaction. Previously, such PM-AM conversion has been extensively studied in a two-level system. The three-level Lambda system has attracted much attention in recent years due to its relevance to quantum memory, magnetometers and atomic clocks. We investigate PM-AM in this system with both random phase noise and modulated phase "noise". Atomic dynamics from both ground and excited states can be revealed from the output intensity noise spectrum. Responses of the system to noise show resonance behavior distinct from a two-level system. For the modulated noise case, adiabatic and nonadiabatic regimes were identified. In particular, using the intensity cross-correlation of the two optical fields as an observable leads to subnatural spectrum for the transition between the two ground states. We will present experimental and theoretical results.

$^1$This work is supported by NSFC.

K1.00007 ABSTRACT WITHDRAWN —
K1.00008 Improved characterization of the A-state of lead monofluoride and measurement of its dipole moment. JAMES COKER, TAO ZH, YANG, JOHN E. FURNEAUX, NEIL E. SHAFER-RAY, University of Oklahoma, HOMER L. DODGE DEPT. OF PHYSICS AND ASTRONOMY TEAM — Lead monofluoride (PbF) is an attractive candidate for measurement of the electric dipole moment of the electron (eEDM) because of its small g-factor and its large enhancement factor [1]. In order to measure the eEDM with PbF, broad and accurate knowledge of its spectroscopic constants is needed. Although the ground (X1) state constants are known to 100 kHz precision [2], the excited states have not been as precisely characterized. A promising state for hyperfine optical detection of the X1 state is the A state [3]. Using a time-of-flight detection scheme described in the work, we present new spectroscopic data of isolated 208Pb19F. The analysis of which yields constants of the A state and molecular dipole moments of the X1 and A states to new precision.


K1.00009 Advances in experimental spectroscopy of Z-pinch plasmas and applications1. V.L. KANTSYREV, A.S. SAFRONOVA, U.I. SAFRONOVA, I. SHRESTHA, M.E. WELLER, G.C. OSBORNE, V.V. SHLYAPTSEVA, P.G. WILCOX, A. STAFFORD, University of Nevada, Reno — Recent advances in experimental work on plasma spectroscopy of Z-pinches are presented. The results of experiments on the 1.7 MA Z-pinch Zebra generator at UNR with wire arrays of various configurations and X-pinches are overviewed. A full x-ray and EUV diagnostic set for detailed spatial and temporal monitoring of such plasmas together with theoretical support from relativistic atomic structure and non-LTE kinetic codes used in the analysis are discussed. The use of a variety of wire materials in a broad range from Al to W provided an excellent opportunity to observe and study specific atomic and plasma spectroscopy features. In addition, the applications of such features to fusion and astrophysics will be considered.

1This work was supported by NNSA under DOE Cooperative Agreements DE-FC52-06NA27586 and DE-FC52-06NA27588, and in part by the Grant DE-FG02-08ER54951.

K1.00010 Energy levels and radiative rates for transitions in Ti VI1. KANTI AGGARWAL, FRANCIS KEENAN, Queen’s University Belfast, Northern Ireland, UK, ALFRED Z. MSEQANE, Clark Atlanta University, Atlanta GA — Energies for 568 levels among the n=3-5p^2d-5p^3s^4f configurations of Ti VI are calculated using the GRASP (General-purpose Relativistic Atomic Structure Program) code, which is based on the multi-configuration Dirac-Fock (MCFD) method. Additionally, radiative rates are calculated for all types of transitions, namely electric dipole (E1), electric quadrupole (E2), magnetic dipole (M1), and magnetic quadrupole (M2). Lifetimes are also calculated for all the levels and extensive comparisons are made with the earlier available data as well as with other parallel calculations from the FAC (Flexible Atomic Code). Discrepancies for several levels with the earlier calculations of Mohan et al., (ADNDT 93 105 (2007)) are highlighted.

1Supported by DOE Office of Science and AFOSR

K1.00011 The calculation of generalized oscillator strength densities of Argon by using an eigenchannel R-matrix method. X. GAO, Beijing Comp. Sci. Res. Center, China, J.M. LI, Shanghai Jiao Tung U./Tsinghua U., China — Understanding the detailed dynamics of electron-ion interactions is of fundamental importance to various plasma applications in the fields of astrophysics, fusion energy researches and so on. Theoretical computations should play indispensable role to satisfy needs. Using our modified R-matrix code R-Eigen, we can directly calculate the short-range scattering matrices with good analytical properties in the whole energy regions, from which we can obtain all energy levels and the related scattering cross sections with accuracies comparable with spectroscopic precision. With the corresponding high-quality eigenchannel wavefunctions, various transition matrix elements can be readily calculated, such as the generalized oscillator strength densities (GOSD). The GOSD is directly related with the high-energy electron impact excitation cross sections. In eigenchannel representation, the GOSD curves of the excited states in an eigenchannel form a surface, which is a smooth function of the momentum transfers and the excitation energies. From such smooth GOSDs, we can obtain the generalized oscillator strength of any specific excited state through multichannel quantum defect theory, e.g. infinite Rydberg (including strongly perturbed one), autoionization and continuum states. As an example, we will present our recent calculation results of Ar, which are in good agreement with available benchmark experiments.

K1.00012 PHOTON INTERACTIONS WITH ATOMS, IONS, AND MOLECULES II

K1.00013 Analytical Description of Laser Assisted Electron Scattering Plateau Spectra for Elliptical Polarization1. ALEXANDER V. FLEGEL, The University of Nebraska, USA, MIKHAIL V. FROLOV, NIKOLAI L. MANAKOV, Voronezh State University, Voronezh, Russia, ANTHONY F. STARACE, The University of Nebraska, USA — We present an analytic description of laser-assisted electron scattering (LAES) for the case of an elliptically polarized laser field. A closed-form analytic formula describing plateau features in LAES is derived quantum mechanically in the low-frequency limit. This formula provides an analytic explanation for the oscillatory patterns of LAES cross sections in the high-energy part of the LAES spectra. This formula generalizes the result for a linearly polarized laser field presented in [1] to the case of elliptical polarization and confirms the possibility of factoring the LAES cross section into the product of two atomic factors involving the field-free cross sections for elastic electron-atom scattering and a factor (insensitive to atomic parameters) describing the elliptically polarized laser-driven motion of the electron. These results provide a fully quantum justification of the classical rescattering scenario for LAES in an elliptically polarized laser field.

1This work was supported in part by RFBR Grants No. 09-02-00541 and No. 10-02-00235, and by NSF Grant No. PHYS-0901673.

K1.00014 Stimulated cooling of molecules on multiple rovibrational transitions with coherent pulse trains1. EKATERINA ILINOVA, JONATHAN D. WEINSTEIN, ANDREI DEREVIANKO, Physics Department, University of Nevada, J.D. WEINSTEIN RESEARCH GROUP, EXPERIMENTAL ATOMIC, MOLECULAR, & OPTICAL PHYSICS TEAM, A. DEREVIANKO RESEARCH GROUP, THEORETICAL ATOMIC PHYSICS TEAM — We propose a method of stimulated laser cooling of diatomic molecules by counter-propagating x-trains of ultrashort laser pulses. The cooling cycles occur on the rovibrational transitions inside the same ground electronic manifold, thus avoiding the common problem of radiative branching in Doppler cooling of molecules. By matching the frequency comb spectrum of the pulse trains to spectrum of the R-branch rovibrational transitions we show that stimulated cooling can be carried out on several rovibrational transitions simultaneously, thereby increasing number of cooled molecules. The exerted optical force does not rely on the decay rates in a system and can be orders of magnitude larger than the typical values of scattering force obtained in conventional Doppler laser cooling schemes. http://arxiv.org/pdf/1201.1015.pdf

1This work was supported in part by the NSF and ARO.
1. J. Colgan, Los Alamos National Laboratory, MICHAEL PINZOLA, Auburn University — The time-dependent close-coupling method is used to calculate angular distributions for the triple photoionization of lithium [1]. The angular distributions reveal the preferred break-up patterns for the four-body Coulomb problem. We find that the angular distributions near the peak of the total triple photoionization cross section at 300 eV are complex, with more than one major break-up pattern evident. Further calculations are underway at smaller photon energies nearer the triple ionization threshold and will be reported at the conference.


K.00016 Efficient Collection of Single Photons Emitted from a Trapped Ion into a Single Mode Fiber for Scalable Quantum Information Processing, ANDRE VAN RYNBACH, RACHEL NOEK, TAEHYUN KIM, PETER MAUNZ, JUNGSA亚洲 KIM, Fitzpatrick Institute for Photonics, Electrical and Computer Engineering Department, Duke University — Interference and coincidence detection of two photons emitted by two remote ions can lead to an entangled state between the ions, which is a critical resource for scalable quantum information processing [1]. The success probability of entanglement generation in current experimental realizations is mainly limited by the low coupling efficiency of a photon emitted by an ion into a single mode fiber. Here we consider two strategies to enhance the collection probability and entanglement generation rate of photons emitted from trapped Yb⁺ ions. The first method uses high numerical aperture optics to enhance light collection, where a practical collection probability of over 10% is possible with proper control of aberration. The second method uses a hemispherical optical cavity created between a flat mirror containing a surface trap and a spherical mirror to enhance the spontaneous emission into the cavity mode. We show that fiber coupling efficiency of over 30% is possible using this approach, leading to an improvement in the entanglement generation rate of over four orders of magnitude. We also report on experimental progress towards realizing these two light collection schemes using surface trapped Yb⁺ ions.


K.00017 Investigating the Possibility of Overcoming Photon Loss via Photon-Phonon Interactions, BHASKAR ROY BARHAN, JONATHAN DOWLING, Louisiana State University — In optical quantum information processing, photons are usually routed through optical fibers or waveguides. However, absorption of the photons in the fiber during the transmission introduces errors in the information processing. We model the absorption of photons with the creation of vibrational excitation (phonon) in one of the modes of the fiber, and investigate how the decay rate can be modified with various density of phononic modes and fluctuations in the fiber. Coherence effects are studied in terms of the spectral density of the bath and the resulting decoherence function. Moreover, we analyze the effects of Markovian and non-Markovian environments on the absorption rate and see if well-known open-loop control techniques such as dynamical decoupling can be used, under suitable approximations, to overcome the losses due to the photon absorption.

K.00018 Towards understanding thermodynamics and energy transport in strings of trapped ions, MICHAEL RAMM, THANED PRUTTIVARASIN, ISHAN TALUKDAR, HARTMUT HAEFFNER, UC Berkeley — We report experiments on laser induced heating of ions confined in a linear Paul trap. Specifically, we investigate the mechanism of melting of a crystallized ion chain due to heating by light detuned blue from an atomic resonance. In these experiments, we observe the decay of ion fluorescence as we shine laser light on either the entire ion string or a small subset. From these measurements we hope to extract information on the thermodynamic properties of such Coulomb crystals. Understanding these properties, together with the ability to address individual ions will facilitate the study of excitation transfer dynamics along the chain.

K.00019 STIRAP Production of Rydberg Helium: Effects of Thermal Radiation and Level Multiplicity, PETR M. ANISIMOY, YUAN SUN, HAROLD METCALF, Stony Brook University, Stony Brook, NY 11794-3800 — Stimulated Raman Adiabatic Passage (STIRAP) has been used in a series of experiments to excite Helium atoms to Rydberg states starting from the metastable 2S state. The usual picture of STIRAP in a three level system suggests that experimental efficiency should be nearly 100%, but our measured efficiency was limited to less than 70%. Here we report a detailed model of the STIRAP process in metastable Helium that accounts for the multilevel structure of the transition and effects of thermal radiation that lead to ionization as well as population redistribution among Rydberg states.

1. Supported by ONR

K.00020 Photoionization of free and confined Mg: Evolution of the cross section with depth of the confining well, P. PADUKKA, T.-L. ZHOU, S.T. MANSON, Georgia State University — The photoionization cross sections of the outer 3s² shell of free and confined Mg have been calculated. The Cₓₒ Confined confinement is modeled as an attractive spherical potential of inner radius 5.8 a.u., thickness of 1.89 a.u. and a depth U₀ varying from 0.0 to 0.302 a.u. (corresponding to MgO(2u)). Modified MCHF and HF codes have been used to obtain the single and multi-configuration wave functions, which were calculated self-consistently including the extra confining potential. The photoionization cross sections were calculated using the R-matrix method at both the LS coupling and Breit-Pauli (BP) approximation level. We found that the ionization energy of the Mg ground state increases somewhat with increasing well depth. Moreover, the photoionization cross section of free Mg, which is dominated in the threshold region by doubly-excited nl'nl'' resonances, changes dramatically in the presence of the confining well, partially because many of the near-threshold resonances move below threshold with increasing well depth. In addition the BP calculation shows spin-orbit splitting, significant even at such low Z.

2. This work was supported by NSF and DOE, Office of Chemical Sciences.

K.00021 Attosecond streaking of correlated two-electron transitions, RENATE PAZOUREK, STEFAN NAGLE, Institute for Theoretical Physics, Vienna University of Technology, Austria, EU, JOHANNES FEIST, ITAMP, Harvard-Smithsonian Center for Astrophysics, MA, USA, JOACHIM BURGDORFER, Institute for Theoretical Physics, Vienna University of Technology, Austria, EU — Attosecond streaking is one of the most fundamental processes in attosecond science allowing for a mapping of temporal information to the energy domain. For the measurement of the release time of electrons in atomic photoemission a time-resolution on the sub-100 attosecond time scale could be achieved [Science 328, 1658 (2010)]. The measured time shifts contain timing (or spectral phase) information associated with the Eisenbud-Wigner-Smith (EWS) time delay. Considerable additional time shifts caused by the probing infrared field could be identified on the single-particle level. In this contribution we address the role of electron correlation in the streaking process. We study two-electron systems for which we solve the full time-dependent Schrödinger equation. For final ionic states with small polarizability correlation effects beyond those of the one-photon transition already included in the EWS time delay are absent. However, for shake-up ionization we find an additional streaking time shift due to the correlated dynamics of the dressed bound electron and the streaked continuum electron.
K1.00022 Variation of Structure Profile for Narrow Resonances in Atomic Photoabsorption as Function of Column Density, T.N. CHANG, USC, T.K. FANG, FuJen Catholic U., Taiwan — We present in detail the variation of the structure profiles for narrow doubly excited resonances in atomic photoabsorption at finite temperature as functions of column density of the target atom systems. In particular, we will examine the change in the peak cross sections, the effective full width at half maximum (FWHM) and the effective asymmetry parameter of the theoretically simulated resonance structure as the pressure varies [1]. We will also examine the temperature effects on the structure profile as the pressure varies.


K1.00023 Inner-shell photodetachment from O$^{-1}$. N.D. GIBSON, C.W. WALTER, D.J. MATYAS, A.N. LEBOVITZ, Y.-G. LI, R.M. ALTON, S.E. LOU, Denison University, R.C. BILODEAU, N. BERRAH, Western Michigan U., A. AGUILAR, ALS, LBL, D. HANSTORP, U. of Gothenburg, Sweden — The K-shell photodetachment spectrum of O$^{-}$ has been investigated using the merged ion-photon beam photodetachment technique. O$^{-}$ ions were produced in a Cs sputtered negative ion source (SNICS II) on a Movable Ion Photon Beamline while the photons were produced by the undulator on the Advanced Light Source Beamline 8.0.1. Positive oxygen ions formed by multiple detachment were detected as a function of photon energy. Photoexcitation of a 1s electron leads to a short-lived Feshbach resonance $\sim 3$ eV below the 1s detachment threshold due to the extra stability of the now full 2p$^6$ shell [1]. Energy calibration of the incoming photons, using an inline gas cell, leads to precise energy level assignments for the observed states. The Feshbach resonance is observed near 525 eV in the O$^{2+}$, O$^{3+}$ and O$^{4+}$ channels. Comparisons to inner-shell photoionization of O will be discussed for both experiment [2] and theory [3].


1 Based in part upon work supported by the NSF under Grant Nos. 0757976 and 1068308 and by DOE, OS, BES, Chemical Sciences, Geosciences and Biosciences Divisions. ALS is supported by DOE, OS, BES. DH acknowledges support from the Swedish RC.

K1.00024 Photodissociation and Predissociation of Heavy Molecular Ions, ALEXANDER PETROV, Temple University — In support of experimental efforts to sympathetically cool heavy BaCl$^+$ molecular ions we investigated a detection mechanism for these ions by developing a quantum mechanical model of photodissociation and predissociation to ionic Ba$^+$ and neutral Cl atoms. Photodissociation occurs when the absorption of a photon leads to a transition from the ground electronic state to a repulsive inner wall of an excited potential. Alternatively, photon absorption leads to a transition to a bound state of an excited state followed by predissociation into a third electronic state. We first calculated the ground X and excited A and B potentials and transition dipole moments of the BaCl$^+$ molecule, using CASPT2 method. We then evaluated matrix elements of the dipole moment operator between the initial rovibrational states of the X potential and final scattering states in the repulsive A potential. The photodissociation cross-section is proportional to the square of these matrix elements. We assumed a thermal distribution over rovibrational states of the X potential in order to compare with available experimental data. We then used a coupled channel calculation that involved the B and A excited electronic states coupled by a coriolis interaction to obtain predissociation rates.

1This work is supported by grants of the Air Force Office of Scientific Research and NSF PHY-1005453.

K1.00025 Valence photoionization of small alkaline earth atoms endohedrally confined in C$_{60}^-$: From the many-electron collectivity to single-electron interferences, MOHAMMAD JAVANI, Georgia State University, MECHEN MCCREARY, AAKASH PATEL, Northwest Missouri State University, MOHAMED MADJET, CFEL/DESY, Hamburg, Germany, HIMADRI CHAKRABORTY, Northwest Missouri State University, STEVE MANSON, Georgia State University — Results of a theoretical study of the photoionization from outermost orbitals of Be, Mg and Ca atoms endohedrally confined in C$_{60}^-$ are presented. The fullerene ion-core of sixty C$^{2+}$ ions is smudged into a continuous jellium distribution while the delocalized cloud of carbon valence electrons, plus the encaged atom, are treated in the time-dependent local density approximation (TDLDA) [1]. Systematic evolution of the mixing of outer atomic level with the C$_{60}^-$ band is detected along the sequence. This is found to influence the plasmon-driven enhancement at low energies and the geometry-revealing confinement oscillations from multi-path interferences at high energies in significantly different ways. The study paints the first comparative picture of the atomic valence photo spectra for alkaline earth metallofullerenes in a dynamical many-electron framework [2].

[2] M.Javani et al., to be published.

1Supported by the NSF and US DoE.

K1.00026 Cooper Pair Formation in Acenes, TIM HARTMAN, PAVLE JURANIĆ, SRC, Univ. of Wisconsin - Madison, KELLY COLLINS, Univ. of Evansville, BETHANY REILLY, Univ. of Wisconsin - Madison, NARAYANA APPATHURAI, SRC, Univ. of Wisconsin - Madison, SCOTT B. WHITFIELD, Dept. of Phys. and Astr., Univ. of Wisconsin - Eau Claire, RALF WEHLITZ, SRC, Univ. of Wisconsin - Madison — We have measured the ratio of doubly to singly charged molecular parent ions of benzene, naphthalene, anthracene, and pyrrole over a wide range of photon energies. About 40 eV above the double-ionization threshold, the first three of the above molecules exhibit a hump of very similar shape and magnitude in the double-to-single photoionization ratio, which we attribute to the formation and emission of an electron Cooper pair from a free molecule. Our results suggest that the de Broglie wave of this highly correlated pair of electrons forms a closed loop in the system of overlapping $r$ bonds with a wavelength that matches the distance between neighboring carbon atoms. Pyrrole with its pentagonal structure does not allow the formation of a closed de Broglie wave and, thus, does not exhibit a hump in the ratio. Photoelectron measurements indicate the break-up of the emitted Cooper pair by two electron peaks sitting on top of the mainly U-shaped double-ionization continuum in support of our interpretation.

1The SRC was supported by NSF Grant No. DMR-0537588.
2present address: Paul Scherrer Institute, Switzerland
K1.00027 Dissociative and non-dissociative photo double ionization of hydrocarbon molecules: C2H2 and C2H41, B. GAIRE, P. BRAUN, I. BOCHAROVA, F. STURM, D. HAXTON, A. BELKACEM, TH. WEBER, Lawrence Berkeley National Laboratory, C.L. COCKE, J.R. Macdonald Laboratory, Kansas State University, A. LANDERS, Department of Physics, Auburn University, R. DORNER, University of Frankfurt — Dissociative and non-dissociative ionization is observed when molecules interact with photons of energy near the double ionization threshold. Non-dissociative ionization will lead to a stable dication. The yield of the dication provides more information about the dicationic states involved. We explore the non-dissociative ionization of acetylene and ethylene molecules while employing the Cold Target Recoil Ion Momentum Spectroscopy (COLTRIMS) method. In contrast to the generation of acetylene dications, our measurements indicate that no stable ethylene dication can be produced via photo double threshold. Non-dissociative ionization will lead to a stable dication. The yield of the dication provides more information about the dicationic states involved. We will discuss the role of non-adiabatic effects leading to the instant fragmentation of the ethylene dications into different breakup channels.

K1.00028 Measuring 10 fs dynamics via resonant x-ray pump/x-ray probe spectroscopy1, RYAN COFFEE, MINA BIONTA, NICK HARTMANN, LCLS-SLAC, JAMES CRYAN, JAMES GŁÓWNI, ADI NATAN, PULSE-Stanford, DOUG FRENC, Penn. State, MARCO SIANO, Imperial College, LCLS - AMO42112 COLLABORATION — We used two x-ray pulses to investigate the femtosecond scale molecular response to K-shell resonant excitation in O2. Our results give three perspectives on this dynamic response: 1) sub-10 fs transient bleaching of resonant absorption, 2) a corresponding sub-10 fs evolution of the resonant Auger electron spectrum, and 3) a 10−15 fs evolution of electronic molecular symmetry. The x-ray pulses are tuned to the 531 eV 1s → 2pπ resonance in O2. Upon excitation by the first pulse, further absorption is suppressed until the dynamic molecular valence pulls a new valence state into resonance. The new resonance occurs only after about 5-10 fs and reveals opposite electronic symmetry to the n*. After 15 fs, this newly resonant state has lost molecular symmetry and undergoes atomic-like resonant absorption. We have thus used x-ray pump-probe spectroscopy to build a time-domain picture of the ~10 fs molecular response to x-ray absorption.

K1.00029 Time-Dependent Dirac Equation for Diatomics in SuperIntense Laser Fields - Numerical and Analytical results, ANDRE D. BANDRAUK1, Canada Research Chair, Université de Sherbrooke, FRANCOIS FILLION-GOURDEAU2, Centre de recherches mathematiques — Numerical methods for solving the one-electron diatomic molecular Dirac equation in ultrashort(few cycles) superintense laser pulses are developed without Fermion-doubling. A split-operator method, originally developed for nonrelativistic time-dependent molecular problems is generalized using the method of characteristics [1]. Analytic results are also presented for a superintense static electric field to evaluate relativistic effects in diatomic CREI-Charge Resonance Enhanced Ionization [2].


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K1.00030 Comparison of high-order harmonic generation of Ar atoms and H2 molecules in intense 780 nm laser fields1, DMITRY A. TELNOV, St. Petersburg State University, Russia, SHIH-I CHU, University of Kansas — We analyze the high-order harmonic generation (HHG) of Ar atoms and H2 molecules in 780 nm laser fields with the pulse duration about 30 fs and various peak intensities by means of the self-interaction-free time-dependent density functional theory (TDDFT). Since the ionization potentials of Ar and H2 are close to each other, the cutoff position of the HHG spectra for the specific intensity is expected approximately at the same harmonic order, according to the three-step model. In general, our TDDFT calculations agree with this prediction; however, in the high-energy part of the HHG spectra, the harmonic signal from H2 is considerably lower than that from Ar. On the other hand, the HHG spectrum of Ar has a prominent minimum at the photon energy 50 eV, especially for lower laser intensities. This minimum has the same nature as the well-known Cooper minimum in Ar observed in photoionization cross sections.

1This work is partially supported by DOE and NSF.

K1.00031 Probing the spectral and temporal structures of macroscopic high-order harmonic generation of He in intense ultrashort laser pulses1, PENG-CHENG LI, I-LIN LIU, National Taiwan University, CECIL LAUGHLIN, University of Nottingham, SHIH-I CHU, University of Kansas — We present an accurate study of macroscopic high-order harmonic generation (HHG) from He atoms in intense ultrashort laser pulses. An accurate one-electron model potential is constructed for the description of the He atoms low-lying and Rydberg states. The macroscopic high-order harmonic spectra from He atoms are obtained by solving Maxwell’s equation using macroscopic single-atom induced dipole moment. Macroscopic single-atom induced dipole moment can be obtained by solving accurately the time-dependent Schrödinger equation (TDSE) using the time-dependent generalized pseudospectral method (TDGSP). This method allows accurate and efficient propagation of the wave function with a modest number of spatial grid points, leading to the efficient treatment of the macroscopic propagation effects for HHG. Our results show fine structure and significant enhancement of the intensities of the lower harmonics due to the resonance transitions between bound states. We explain the temporal and spatial characteristics of HHG by means of the wavelet time-frequency analysis. These analyses help to understand the detailed HHG mechanisms from He atoms.

1This work was partially supported by DOE and NSF and by MOE-NSC-NTU-Taiwan.

K1.00032 Time-dependent theory of resonance fluorescence for ultrafast and ultraintense x rays1, STEFANO M. CAVALETTO, ZOLTÁN HARMAN, CHRISTOPH H. KEITEL, Max-Planck-Institut fuer Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany, CHRISTIAN BUTH, Argonne National Laboratory, Argonne, Illinois 60439, USA — The recent development of intense sources of coherent x-ray radiation such as the Linac Coherent Light Source (LCLS) in Menlo Park, California, USA, provides one with an unprecedented way to study nonlinear physics at short wavelengths. In this regard, resonance fluorescence, i.e. the spectrum of photons scattered off atoms and molecules driven by a near-resonant electric field, is expected to play a decisive role. We compute the time-dependent spectrum of resonance fluorescence of a two-level system excited by an ultrashort pulse. We allow for inner-shell hole decay widths and destruction of the system by further photoionization. This two-level description is employed to model neon cations strongly driven by LCLS light tuned to the 1s 2pπ−1 → 1s−1 2pπ transition at 848 eV: x rays induce Rabi oscillations which are so fast that they compete with Ne 1s-hole decay. First, we predict resonance fluorescence spectra for chaotic pulses generated at present-day LCLS; second, we explore the exciting novel opportunities offered by Gaussian pulses which will become available in the foreseeable future with self-seeding techniques. In the latter case, we predict a clear signature of Rabi flopping in the spectrum of resonance fluorescence.

1C.B. was funded by the Office of Basic Energy Sciences, Office of Science, U.S. Department of Energy, under Contract No. DE-AC02-06CH11357.
**K1.00033 Algorithm for Reconstruction of 3D Molecular Structure from Diffraction Patterns of Laser-Aligned Molecules**, JIE YANG, CHRISTOPHER HENSLEY, MARTIN CENTURION, University of Nebraska - Lincoln — Ultrafast electron diffraction from laser-aligned gas molecules is a promising method for the determination of 3D molecular structures. Reconstruction algorithms for diffraction patterns of perfectly aligned molecules have been widely studied theoretically. However, under experimental conditions only partial alignment can be achieved and the existing algorithms do not perform well when the alignment is not perfect. We develop a method to reconstruct the 3D structure of molecules with cylindrical symmetry from electron diffraction patterns of partially-aligned molecules. The evolutionaryary algorithm assumes a known angular distribution, which can be calculated numerically using existing theory for laser-alignment and verified by comparison with the data. Selecting CF$_3$ as the cylindrically symmetric molecule, diffraction patterns from multiple alignment angles are used to reconstruct a single diffraction pattern corresponding to perfect alignment. The molecular structure can then be recovered from this pattern with no prior structural information required. Our results are in good agreement with previous models of CF$_3$I structure.

**K1.00034 Double-slit interference in H$_2^+$ subjected to ultrashort x-ray radiation**, ETHAN SECOR, XIAOXU GUAN, KLAUS BARTSCHAT, Drake University, BARRY I. SCHNEIDER, National Science Foundation — Extending our earlier work [1], we consider the double-slit interference effect [2,3] in the H$_2^+$ ion irradiated by intense short x-ray laser pulses with central photon energies from 200-500 eV. The time-dependent Schrödinger equation in prolate spheroidal coordinates is solved to extract the angle-differential cross section of the photoelectron. The spatial coordinates are discretized by means of a finite-element discrete-variable representation. We discuss the confinement effect [3] in the parallel geometry, in which the emission mode of the photoelectron along the laser polarization direction is dynamically forbidden. This confinement appears periodically, with the details depending on both the momentum of the electron and the internuclear separation. On the other hand, the effect disappears in the perpendicular geometry. We compare our results to those obtained from a simple plane-wave model based on time-independent perturbation theory.


1Work supported, in part, by the United States National Science Foundation under PHY-1068140 and the XSEDE allocation TG-PHY090031.

**K1.00035 Dissociative single ionization of CO$^+$ molecular ions into C$^{2+}$ + O by intense laser pulses**. NORA G. JOHNSON, J. MCKENNA, A.M. SAYLER, B. GAIRE, M. ZOHRAEI, K.D. CARNES, I. BEN-ITZHAK, J.R. Macdonald Laboratory, Physics Department, Kansas State University — The charge asymmetric dissociative ionization (CADI) of a CO$^+$ molecular ion beam into C$^{2+}$ + O was studied by 7 and 40 fs intense ($10^{14}$ W/cm$^2$) laser pulses with both linear and circular polarization. Using a three-dimensional coincidence imaging technique, we detected both charged and neutral fragments. The measured kinetic energy release and angular distributions allow us to investigate the pathway leading to this CADI channel. Preliminary analysis suggests that the CO$^+$ is first excited in the leading edge of the laser pulse and later ionized to the C$^{2+}$ + O dissociative curve. We speculate that the initial stretching allows the molecule to be ionized beyond a curve crossing between the C$^{2+}$ + O and high lying C$^+$ + O$^+$ potentials, therefore enabling dissociation into the otherwise hard-to-reach CADI channel. This possible pathway and the dependence on intensity, polarization, and pulse duration will be discussed.

1Supported by the Chemical Sciences, Geosciences, and Biosciences Division, Office of Basic Energy Sciences, Office of Science, U.S. Department of Energy.

**K1.00036 Tracking Quantum Populations in Non-Sequential Double Ionization of Atoms**. STAN HAAN, CHRISTIAN WOOLLEY, KATHERINE SHOMSKY, Calvin College — We use one-dimensional quantum models to consider nonsequential double ionization of atoms in intense laser fields. We examine in particular the mixing of quantum states that is induced by the oscillating laser field. This mixing helps explain why classical models work so well — even prior to recollision, the inner electron is in a mixture of ground and excited states. Recollision can change this mixture without needing a threshold energy for excitation from the ground to first excited state.

1This work supported by NSF Grants PHY-9069984 and OCI-0722819.

**K1.00037 Femtosecond transparency in the extreme ultraviolet**. MICHAL TARANA, CHRIS H. GREENE, Department of Physics and JILA, University of Colorado, Boulder, Colorado 80309-0440, USA — Electromagnetically induced transparency-like behavior in the extreme ultraviolet (XUV) is studied theoretically, including the effect of intense 800 nm laser dressing of He 2s2p$^1 P^o$ and 2p$^2 2S^o$ autoionizing states. We present an ab initio solution of the time-dependent Schrödinger equation in an LS-coupling configuration interaction basis set. The method enables a rigorous treatment of optical field ionization of these coupled autoionizing states into the $N = 2$ continuum in addition to $N = 1$. Our calculated transient absorption spectra show the formation of the Autler-Townes doublet in the presence of the dressing laser field. The presented results are in encouraging agreement with experiment [1].


1This work was supported in part by the Department of Energy, Office of Science.

**K1.00038 The Phasemeter**. A.M. SAYLER, T. RATHJE, M. MÖLLER, D. ADOLPH, W. MÜLLER, D. HOFF, G.G. PAULUS, Institut für Optik und Quantenelektronik and Helmholz Institut Jena, Max-Wien-Platz 1, 07743 Jena, Germany, INSTITUT FÜR OPTIK UND QUANTELEKTRONIK AND HELMHOLTZ INSTITUT TEAM — Intense few-cycle (4-6 fs) laser pulses at 790 nm are now being used in a wide variety of applications, including the production of attosecond extreme-ultraviolet (XUV) pulses. Since these experiments are sensitive to the electric field of the laser light, the characterization and control of the waveform is critical for the understanding and manipulation of these interactions. We expand the usage of a stereographic laser-induced above-threshold ionization measurement of Xe (CEPM), i.e. the same technique optimized to provides precise, real-time, every-single-shot carrier-envelope phase and pulse length measurements of ultrashort laser pulses. This technique was restricted to sub-8 fs laser pulses, however, by combining the CEPM with polarization gating; the acceptance region has been extended to a pulse length of 12 fs. Together with real-time circuit, the CEPM also allows for improved the carrier-envelope phase stabilization of few-cycle laser pulse systems by 25%.

1This work was supported by LaserLab Europe and a grant PA 730/4 from the German Research Foundation (DFG).
K1.00039 Carrier-envelope phase effects in few-cycle ionisation of atomic hydrogen. DAVID KIELPINSKI, W.C. WALLACE, M.G. PULLEN, O. GHAFUR, D.E. LABAN, A.J. PALMER, Australian Attosecond Science Facility and Centre for Coherent X-Ray Science, Griffith University, G.F. HANNE, Westfälische Wilhelms-Universität, Münster, A.N. GRUM-GRZHIMAILO, Drake University and Moscow State University, K. BARTSCHAT, Drake University, I.A. IVANOV, A.S. KHEIFETS, Australian National University, X.-M. TONG, Tsukuba University, H.M. QUINEY, Centre for Coherent X-Ray Science, University of Melbourne, I.V. LITVINYUK, R.T. SANG, Australian Attosecond Science Facility and Centre for Coherent X-Ray Science, Griffith University. — The control of strong-field photoionization with laser carrier-envelope phase (CEP) is the key enabling technique for attosecond pulses. Current results point the way toward accurate calibration of absolute laser CEP by means of the uniquely calculable hydrogen system.

K1.00040 The population trapping of Rydberg states in microwave ionization. ALEXANDR ARAKELYAN, STEFAN SALANSKI, THOMAS GALLAGHER, University of Virginia. — Previously, it was reported that when Rydberg atoms of Li are excited in the presence of a 17 or 36 GHz microwave field, the atoms remain bound even if the excitation is above the limit. We present another, more sensitive way to explore such microwave stabilization. Atoms of Li are excited to a high np Rydberg states during a 200 ns 38 GHz microwave pulse and surviving bound states are detected. As the last transition frequency is swept, the stable states spaced by an integer number of microwave photons are evident from about -2000 GHz below the ionization limit (the energy of the zero field of n=45 state) up to 200 GHz above the limit with a microwave field of 85 V/cm. The interesting result is that these states exist even for binding energies in excess of 1100 GHz, which corresponds to a state of n=55, with a Kepler frequency of 38 GHz. Similar weakly bound final states are observed if bound Rydberg states are excited in zero field and then exposed to the microwave pulse. In this case the population transfer by a microwave pulse to the high lying states is about 10% of the total number of atoms initially excited to the Rydberg state, even when the microwave field is high enough that no other bound states survive.


3This work has been supported by The National Science Foundation

K1.00041 ATOMIC, MOLECULAR, AND CHARGED PARTICLE COLLISIONS II —

K1.00042 An integro-differential transform to analytically reduce H₂ molecular integrals. JACK STRATON, Portland State University. — Molecular integrals that have a coordinate dependence akin to the bonding H₂ wave function are often carried out one-by-one, using hyper-spherical coordinates. These calculations are often carried out one-by-one, using hyper-spherical coordinates. The Jacobi coordinates or conical coordinates or Jacobi coordinates. An alternative strategy is to extend the general result developed by the author for evaluating integrals of any number of products of multivariate ground-state or excited atomic wave functions, Coulomb or Yukawa potentials, and Coulomb-waves to include the H₂ molecular wave function. Modifications for semi-infinite integrals that terminate on a surface such as a Scanning Tunneling Microscope sample are also discussed.


K1.00043 Positron Reaction Microscope. D.W. MUELLER, C. LEE, C. VERMET, S. ARMITAGE, University of North Texas, D. SLAUGHTER, Lawrence Berkeley, L. HARGRAVE, Cal-State Fullerton, A. DORN, Max Plank Institute fur Kern Physik-Heidelberg, J. BRUNTON, Australian National University, S.J. BUCKMAN, Australian National University, J.P. SULLIVAN, Australian National University, CENTRE FOR ANTIMATTER MATTER STUDIES COLLABORATION. — We are developing a positron reaction microscope to measure kinematically complete ionization reactions of atoms and molecular ions. The positron impact is used to measure the slow positron beamline at the ARC Centre for Antimatter Matter Studies (CAMS) node at the Australian National University (ANU). This project is a collaboration among the University of North Texas, CAMS, and the Max Plank Institute fur Kern Physik in Heidelberg. Initial measurements and apparatus calibration will be performed using electrons. For positron measurements, the apparatus will be rolled into position on the slow positron beamline at the CAMS site at ANU.

K1.00044 Heavy-Rydberg ion-pair formation in collisions of Rydberg atoms with attaching targets. CHANGHAO WANG, MICHAEL KELLEY, F. BARRY DUNNING, Rice University. — Collisions between K(np) Rydberg atoms and electron attaching targets can lead to the creation of heavy-Rydberg ion-pair states comprising a weakly-bound positive-negative ion pair orbiting at large internuclear separations. The lifetimes of such states and their correlation with binding energy and the channels available for decay, can be controlled by varying n, the Rydberg atom velocity, and the target species, are being investigated. The ion-pair states are produced in a small collision cell and allowed to exit to form a beam that passes between a pair of electrodes where their number and binding energy distribution is determined by electric field induced dissociation. Ion-pair production is analyzed with the aid of a Monte Carlo collision code that models both initial Rydberg electron capture and the subsequent evolution of the product ion pair. Research supported by the Robert A Welch Foundation.

K1.00045 Three-Body Recombination of Ultracold Atoms Treated Classically. STEVE RAGOLE, CHRIS GREENE, University of Colorado, Boulder. — Three-body recombination is an important process in quantum gases. A six-dimensional classical simulation of the process has been formulated and implemented numerically, and Newtonian results for the generalized recombination cross-section have been calculated. Preliminary comparisons to quantum mechanical results will be discussed at the meeting, and animations of the recombination trajectories will be presented and interpreted.

1This work was supported by NSF
K1.0046 Avalanche Mechanism for Multiple Atom Loss near an Efimov Atom-Dimer Resonance. ERIC BRAATEN, DANE SMITH, Ohio State University — Three-body recombination in ultracold trapped atoms produces an energetic atom and dimer that can escape from the trap. If the scattering cross sections are sufficiently large, rescattering of the escaping atoms and dimer can create an avalanche of lost atoms. As shown by Zaccanti et al., this mechanism can be enhanced by the existence of an Efimov trimer near the atom-dimer threshold. We use Monte Carlo methods to generate cascades initiated by recombination events. The energy dependence of the universal atom-dimer cross section associated with a large scattering length is fully taken into account. Every atom in the cascade either escapes or remains trapped, in which case its energy is eventually converted into heat. We calculate the average number of atoms lost and the heat produced by the avalanche mechanism as functions of the atom-atom scattering length. The existence of an Efimov trimer near the atom-dimer threshold can produce a relatively narrow peak in the atom loss rate.

K1.0047 A diabatic hyperspherical method for three-body recombination rates: application to H + H + He → H₂ + He. NICOLAIS L. GUEVARA, Department of Physics. Kansas State University, W. BLAKE LAING, Department of Physics & Astronomy, Rowan University, BRET D. ESRY, Department of Physics. Kansas State University — The formation of the hydrogen molecule through three-body recombination reactions was very important in the early universe. During the last decade, we have seen important progress in the calculation of three-body recombination rates. Most of them, however, have been focused on ultracold temperatures. Here, we present a method to study three-body recombination reactions that can handle temperatures of astrophysical interest and also many diatomic states. Our method introduces diabatic states in hyperspherical coordinates based on physical arguments to simplify the numerical calculations. In the present work, we have studied the reaction H + H + He → H₂ + He in order to test the utility and efficiency of our approach. Prospects for extending our method to other systems will be discussed.

Supported by the National Science Foundation

K1.0048 Electron-impact ionization of Al²⁺ and Al⁺, DI WU, S.D. LOCH, C.P. BALLANCE, SHAHAB ADDEL-NABY, M.S. PINDZOLA, Department of Physics, Auburn University, Auburn, Alabama, 36849 — Electron-impact ionization cross sections are calculated for Al²⁺ and Al⁺. The non-perturbative R-Matrix with PseudoStates (RMPS) method was used to calculate the direct ionization of the 3s and 2p subshells and the indirect ionization of the 2p subshell for Al²⁺ in a single, comprehensive calculation. This model agrees well with the experimental measurement of Thomason and Peart [1]. For Al⁺, the RMPS and time-dependent close coupling methods are used to calculate cross sections for incident energies ranging from 5 to 30 eV. The non-perturbative close-coupling methods are found to be substantially lower than the perturbative distorted-wave cross sections due to electron correlation effects in both the direct ionization and indirect excitation-autoionization contributions. In addition, the close-coupling cross sections are found to be in good agreement with experiment [2].


This work was supported in part through grants from the U S Department of Energy and NASA. The computational work was carried out at NERSC, Oakland, California.

K1.0049 Interchannel coupling effects in multi-channel potential scattering, DMITRI SOKOLOVSKI, University of Basque Country, Spain and Queen’s University, UK, ZINEB FELFLI, ALFRED Z. MZEZANE, Clark Atlanta University — There has been an increasing interest in resonance effects which arise when collision partners form a long-lived intermediate complex. An isolated resonance can be associated with a pole of the scattering matrix either in the complex energy or the complex angular momentum (CAM) plane. Observables of interest such as integral and differential cross sections are conveniently described by CAM (Regge) poles. Here a direct method for calculating Regge pole positions and residues, suitable for systems with a relatively small number of channels is proposed. The method is applied to a simple model designed to mimic electron-atom scattering at energies between the first and the second excitation thresholds. It is shown that interchannel coupling splits degenerate Regge trajectories into ones corresponding approximately to the two adiabatic potentials used. Nonadiabatic effects are found to be responsible for self-intersection of a Regge trajectory [1], not observed in single channel scattering. Envisioned is the possibility to probe Regge resonances and Feshbach resonances occurring in Bose-Einstein condensates.


Research supported by DOE Office of Science; AFOSSR and Army Research Office

K1.0050 Electron-helium laser-assisted free-free scattering with variable laser polarization, B.A. DEHARAK, Illinois Wesleyan University, BENJAMIN NOSARZEWSKI, Cornell University, MAHSA SIAVASHPOURI, N.L.S. MARTIN, University of Kentucky. We report a series of experiments that examine electron-helium scattering in the presence of an Nd:YAG laser field of 1.17 eV photons. In previous experiments, we examined the range of incident electron energies from 50 eV to 350 eV, and found the results to be in good agreement with the Kroll-Watson approximation (KWA). In these experiments the laser polarization was fixed relative to the scattering plane. Experiments are now being carried out where, at each electron energy, the direction of the polarization is varied within a plane perpendicular to the scattering plane. Of particular interest is the case where the laser is perpendicular to the scattering plane for which the KWA predicts vanishing cross section. Other workers have found that the KWA tends to be inaccurate for those cases when it predicts small cross sections.

Work supported by NSF Grant PHY-0855040 (NLSM).

K1.0051 P-wave electron-hydrogen scattering, ANAND BHATIA, NASA/Goddard Space Flight Center — A variational wave function incorporating short range correlations via Hylleraas type functions plus long-range polarization terms of the polarized orbital type but with smooth cut-off factors has been used to calculate P-wave phase shifts for electron-hydrogen scattering. This approach gives the direct r⁻¹ potential and a non-local optical potential which is negative definite. The resulting phase shifts have rigorous lower bounds and the convergence is much faster than those obtained without the modification of the target function. Final results will be presented at the conference.
K1.00052 Progress Report on O(1D) production from oxygen-containing molecules. WILLIAM MCONKEY, WLADEK KEDZIERSKI, JEFF HEIN, University of Windsor — O(1D) is an important species in the earth’s atmosphere giving rise to the well known oxygen red lines at wavelengths of 630.0 and 636.4 nm from the upper atmosphere and strongly influencing stratospheric photochemistry. O(1D) is metastable and is difficult to detect selectively in the laboratory. We have developed techniques and instrumentation involving a solid Ne matrix at 10K that is sensitive to this species through the formation of excited exciters (NeO*) which immediately radiate. Using a pulsed electron beam and time-of-flight techniques we have measured relative cross sections as a function of impact energy electron for a number of targets including N2O and CO2. Threshold energy data are used to gain information about the parent molecular states.

3The authors thank NSERC and CFI, (Canada) for financial support.

K1.00053 Electronic excitation of furan molecules by low energy electron impact. GABRIELA Serna, LEIGH HARGREAVES, MURTADHA A. KHAKOO, California State University Fullerton, Physics Department, CA, 92834, MARIA CHRISTINA A. LOPES, Federal University of Juiz de Fora MG, Brazil, ROMARLY DA COSTA, Federal University ABC, Sao Paulo, Brazil, MARCIO H.F. BETTEGA, Federal University of Parana, Curitiba, Brazil, MARCO A.P. LIMA, State University of Campinas, Unicamp, Brazil. — Absolute differential and integral cross sections are presented for electron impact excitation of the 3B2 and 3A1 states of furan. The energy range of the present data set was 5-15eV. The measurements were normalized relative to the elastic cross section data of [1] and are compared to new calculations employing a multi-state Schwinger Multichannel approach with pseudopotentials [2]. The differential cross sections are peaked in the backwards direction, which is characteristic for optically forbidden transitions. Agreement between experiment and theory is good in some cases, although discrepancies remain, particularly above the ionization threshold. These differences are currently being investigated. The influence of polarization and multichannel coupling effects is also examined.


K1.00054 Momentum imaging of dynamical processes in dissociative electron attachment: resolving a mystery in CO2. DANIEL SLAUGHTER, HIDEHITO ADANIYA, THOMAS RESCIGNO, DANIEL HAXTON, Lawrence Berkeley Lab, ANN OREL, University of California, Davis, DANIEL MCCURDY, ALI BELKACEM, Lawrence Berkeley Lab, and CHEMICAL SCIENCE DIVISION TEAM. — We will report recent developments and experimental results of the dynamics of dissociative electron attachment (DEA) to CO2 by momentum imaging of the dissociating transient anion resonance. A 4-π solid angle momentum spectrometer of the experimental apparatus, consisting of a pulsed electron beam, an electrostatic lens and a time-and position-sensitive detector, enables the measurement of the full 3D momentum distribution of dissociating negative ions. When combined with the spatial orientation of the incident electron, determined by ab initio theoretical calculations, the ion momentum distribution yields a wealth of information relevant to the dynamical study of DEA. Recent experimental results for CO2 have confirmed the known three DEA resonances, leading to CO + O-, at 4.4, 8.2, 13.0 eV electron energies, where we have discovered unique momentum distributions specific to each resonance. Combining these experimental results with ab initio theoretical calculations, we have resolved a long standing misconception for the 8.2 eV and 4 eV resonances.

1Department of Energy

K1.00055 Potential energy surfaces of metastable CO2− for dissociative electron attachment. DANIEL HAXTON, Chemical Sciences, Lawrence Berkeley National Lab, C.W. MCCURDY, LBNL; UC Davis, Dept. of Chemistry, TOM RESCIGNO, Lawrence Berkeley National Laboratory, SPIRIDOULA MATSIKA, Temple University — I present potential energy surfaces of the metastable electronic states of the CO2− anion relevant to dissociative electron attachment, which proceeds via two electronic states at approximately 4 and 8eV. DEA of CO2 has been studied by many authors [including Dressler and Allan, Chem Phys 92, 449 (1985); Huels, Parenteau, Cloutier, and Sanche, J Chem Phys 103, 6775 (1995)], but the specific mechanisms of DEA to CO2 have not been fully elucidated. The anion system is relevant in other contexts including catalytic conversion of CO. In a combined theoretical and experimental study of this system, we have established [J Phys B 44, 205203 (2011)] that the 8eV resonance is indeed a Feshbach resonance of 2Πu symmetry. The system of potential energy surfaces of this pair of states and the pair of states correlating to the 4eV 2Πu, shape resonance that is responsible both for DEA and vibrational excitation at this energy, as well as that of the lowest energy anion state that begins as a virtual state at linear geometry and becomes the bound bent CO2−, explain the mechanisms of DEA and provide guidance to understand the current results of D. Slaughter, A. Belkacem et al which include angular and kinetic energy distributions of the fragments.

2This work was performed under the auspices of the US DOE by LBNL under contract DE-AC02-05CH11231

K1.00056 Low-Energy Electron Scattering by Sugarcane Lignocellulosic Biomass Molecules. ELIANE OLIVEIRA, CTBE/CNPMM, SERGIO SANCHEZ, MARCIO BETTEGA, UFPR, MARCO LIMA, CTBE/CNPMM, MARCIO VARELLA, USP. — The use of second generation (SG) bioethanol instead of fossil fuels could be a good strategy to reduce greenhouse gas emissions. However, the efficient production of SG bioethanol has been a challenge to researchers around the world. The main barrier one must overcome is the pretreatment, a very important step in SG bioethanol aimed at breaking down the biomass and facilitates the extraction of sugars from the biomass. Plasma-based treatmet, which can generate reactive species, could be an interesting possibility since involves low-cost atmospheric-pressure plasma. In order to offer theoretical support to this technique, the interaction of low-energy electrons from the plasma with biomass is investigated. This study was motivated by several works developed by Sanche et al., in which they understood that DNA damage arises from dissociative electron attachment, a mechanism in which electrons are resonantly trapped by DNA subunits. We will present experimental results for low energy scattering by sugarcane biomass molecules, obtained with the Schwinger multichannel method. Our calculations indicate the formation of π∗ shape resonances in the lignin subunits, while a series of broad and overlapping σ∗ resonances are found in cellulose and hemicellulose subunits. The presence of π∗ and σ∗ resonances could give rise to direct and indirect dissociation pathways in biomass. Then, theoretical resonance energies can be useful to guide the plasma-based pretreatment to break down specific linkages of interest in biomass.

3Supported by FAPESP, CAPES and CNPq.

K1.00057 Positron scattering measurements from Krypton and Xenon. JAMES SULLIVAN, JOSHUA MACHACEK, CASTEN MAKOCHKEANWA, ADRIC JONES, PETER CARADONNA, DANIEL SLAUGHTER, STEPHEN BUCKMAN, Australian National University, DENNIS MUELLER, University of North Texas — As a part of a comprehensive program of low energy positron scattering, measurements have been made for a variety of scattering processes from the heavier rare gases, krypton and xenon. In the case of positron scattering, there have been large disagreements between different experiments, and experimental and theoretical determinations of scattering cross sections for these targets. A wide range of low energy positron scattering measurements is now possible, thanks to the development of the Surko trap and beam system, which provides a high energy resolution source of positrons [1-3]. The resulting positron beam is magnetised, and techniques developed for measuring cross sections in the magnetic fields mean that a wide range of scattering processes are now be investigated with high accuracy. This presentation will present measurements of total scattering, positronium formation and elastic differential scattering for both of these targets. The strongly forward peaked nature of the differential cross sections will be highlighted, especially as it relates to previous disagreements between different experimental measurements of the grand total cross section. In the case of positronium formation, the difference between present measurements and previous studies will also be discussed. [1] T. Murphy and C. M. Surko, Phys. Rev. A 46, 5696 (1992) [2] S. J. Gilbert et al., Appl. Phys. Lett. 70, 1944 (1997) [3] P. Sullivan et al. Phys. Rev. A 66, 042708 (2002)
K1.00058 Direct and indirect annihilation channels in positron-atom scattering1. SERGEY YAKOVLEV, St-Petersburg State University, VLADIMIR ROUDNEV, University of Kentucky, VITALY GRADUSOV, St-Petersburg State University, MICHAEL CAVÁGERO, University of Kentucky — We study positron-atom scattering on the base of Faddeev-Merkuriev equations in configuration space. Decomposition of the wave function into components corresponding to different asymptotic channels provides a way to separate the direct annihilation channel from the annihilation through positronium formation. The first, short time scale process corresponds to direct collisions between the positron and the atomic shell. The second process has a time scale of the positronium half-life. The result is illustrated with positron-Hydrogen scattering calculations at low energies.

1Supported by NSF grant PHY-0903956, St-Petersburg State University grant 1838/1

K1.00059 Modeling X-ray Emission due to Charge Exchange1, P.C. STANCIL, J.L. NOLTE, R.L. PORTER, R.L. SHELTON, Y. WU, University of Georgia, D.R. SCHULTZ, University of North Texas, Y. HUI, Oak Ridge National Laboratory, M.J. RAKOVIC, Grand Valley State University, G.J. FERLAND, University of Kentucky, H.P. LIEBERMANN, R.J. BUENKER, Bergische Universität Wuppertal — Since the advent of Cravens’ [1] proposal that the observed X-ray emission from comet Hyakutake was due to charge exchange (CX) of highly-charged solar wind ions with cometary neutrals, the CX-mechanism has been identified as a possible dominant contributor to the X-ray emission observed in the heliosphere, planetary exospheres, the geocorona, supernova remnants, starburst galaxies, and molecular cooling flows in galaxy clusters. To provide reliable CX-induced X-ray spectra models to simulate these and other astrophysical environments, we have undertaken a project to compute quantum-state-resolved CX cross sections of highly-charged ions colliding with H and He. Here we summarize current results for C(5−6)+, N(4−5)+, and O(6−8)+ obtained with the molecular-orbital close-coupling (CC), atomic-orbital CC, and classical trajectory Monte Carlo methods. Utilizing the theoretical CX cross sections, cascade models are computed to generate X-ray spectra and compared to available measurements and observations. Comparison is also made to models assuming excitation by thermal electrons to identify diagnostics to distinguish CX-induced and electron-impact-induced X-ray emission.


K1.00060 3D imaging of molecular-ion dissociation following slow impact with atomic targets1, B.BERRY, N.G. JOHNSON, W.WOLFF2, A. MAX SAYLER, DAG HATHIRAMANI, JACK W. MASEBERG, SAM FAHRENHOLTZ, K.D. CARNES, I. BEN-ITZHAK, J.R. Macdonald Laboratory, Physics Department, Kansas State University — Collisions between few keV molecular ions and atoms result primarily in collision-induced dissociation (CID) and dissociative capture (DC). The CID process can be a result of vibrational excitation; however, previous experimental efforts were unable to resolve the vibrational process from the competing electronic excitation, complicating comparison with theory. Employing coincidence 3D imaging of the ion beam fragments and recoil ions, we are able to experimentally separate the vibrational (vCID) and electronic (eCID) processes, giving new insight into the vibrational mechanism. We investigate the influence of alignment and orientation of the molecule on eCID and vCID as well as other collision channels. In addition, we address the fate of the target atom following these collisions. A sample of results exploring CID and other processes occurring in such collisions will be presented.

1This work was partially supported by NASA grant NNX09AV46G.
2Permanent address: Instituto de Fisica, Universidade Federal do Rio de Janeiro, Rio de Janeiro 21945-870, RJ, Brazil

K1.00061 QUANTUM OPTICS, MATTER OPTICS, AND COHERENT CONTROL II —

K1.00062 Enhancement of mechanical Q-factors by optical trapping1, J.D. HOOD, K.-K. NI, R. NORTE, D.J. WILSON, S.P. YU, A.M. JAYICH, O. PAINTER, H.J. KIMBLE, California Institute of Technology, Pasadena, CA 91125 — The quality factor (Q) of a mechanical resonator is an important figure of merit for observing quantum behavior. We demonstrate a technique to push the quality factor of a micro-mechanical resonator beyond conventional material and fabrication limits by using an optical lattice to trap a particular motional mode. A majority of the resonator’s energy is stored in the lossless optical potential, thereby strongly diluting the effect of material dissipation. The pendulum-like mechanical resonator consists of a suspended 10 μm diameter, 140 nm thick SiO2 disk attached to the substrate by a single thin tether. The disk is trapped at the intensity maximum of an optical lattice, and we observe a frequency increase of the center of mass from 6.2 KHz to 145 KHz with a 50 fold Q increase to a final value of 5.8 × 105. This technique shows a strong potential in bringing other micro-mechanical resonators, such as SiN membranes, into a low-loss regime where observation of quantum behavior in macroscopic devices at room temperature becomes possible.

1Research Supported by the DARPA ORCHID program, by the DoD NSSEFF program, by NSF Grant PHY-0652914, and by the Institute for Quantum Information and Matter.

K1.00063 Impact of Decoherence on Internal State Cooling using Optical Frequency Combs, SPENCER HORTON, SVETLANA MALINOVSKAYA, Stevens Institute of Technology — We discuss femtosecond Raman type techniques to control molecular vibrations, which can be implemented for internal state cooling from Feshbach states with the use of optical frequency combs. We analyzed the use of an optical frequency comb, with and without modulation, as a viable substitute to the STIRAP process. In our theoretical model we take into account decoherence in the form of spontaneous emission and collisional dephasing in order to ascertain an accurate model of the population transfer in a three level system. We analyze the effects of odd and even chirps of the optical frequency comb in the form of sine and cosine functions on the population transfer. We compared the effects of these chirps to the results attained with a standard optical frequency comb to see if they increase the number of molecules that eventually end up in the final deeply bound state in the presence of decoherence. We also analyzed the inherent phase relation of the collisional dephasing between each of the states. This ability to control the vibrational states of a molecule with an optical frequency comb enables us to create a deeply bound ultracold polar molecule from the Feshbach state.

K1.00064 Coupling phonons and spins in diamond, STEVEN BENNETT, SHIMON KOLKOWITZ, QUIRIN UNTERREITHMEIER, Harvard University, PETER RABL, IQOQI-University of Innsbruck, ANIA BLESZYNSKI-JAYICH, University of California, Santa Barbara, JACK HARRIS, Yale University, MIKHAIL LUKIN, Harvard University — We present theoretical considerations for coupling quantized mechanical motion to the electronic spin of a nitrogen-vacancy (NV) defect center in diamond. In a recent experiment, a single NV spin was used to detect both driven and thermal motion of a magnetic force microscope cantilever at room temperature, reading out the spin state optically. This demonstration raises interesting theoretical questions, such as the feasibility of reaching the strong coupling regime and of measuring the quantum zero-point motion of the cantilever using the NV spin as a detector. We discuss these possibilities for the magnetically coupled system, as well as alternative spin-phonon coupling mechanisms in diamond with prospects for improved magnetometry and mechanical cavity QED.
**K1.00065** Coulomb barrier and exchange interaction in dynamical two-electron systems\(^1\). MAXWELL GREGORE, PAVEL LOUGOVSKI, HERMAN BATELANA, University of Nebraska-Lincoln — Recent electron sources can produce pulses containing multiple electrons that are confined both laterally and longitudinally. Given that the highest reported degeneracy for continuous sources of free electrons is about \(10^{-4}\), it would be interesting to know the degeneracy for these pulses sources. We previously studied one-dimensional two-electron degeneracy \(1\), and now we study three-dimensional two-electron degeneracy as a function of time. Our primary goal is to use this project as a necessary step to studying three-dimensional n-electron degeneracy. Our second goal is to develop a theory that predicts the outcome of Hasselbach’s experiment demonstrating the Hanbury Brown-Twiss Effect \(2\) for free electrons.

\(^1\)We gratefully acknowledge support from NSF.

**K1.00067** Theory of laser cooling of nuclear spins based on coherent population trapping. ADI PICK, MICHAEL GULLANS, YIWEEN CHU, EMRE TOGAN, Harvard University, SUSANNE YELIN, University of Connecticut, MIKHAIL LUKIN, Harvard University — Nuclear spins, associated with \(^{13}\)C impurities in diamond, can be controlled via optical manipulation of localized atom-like impurities. Specifically, spectroscopic techniques involving coherent population trapping were recently used to control and monitor the nuclear state evolution. In this work, we present the physical mechanism which leads to optical pumping of the nuclear spin ensemble into particular nuclear states. We propose an optimized scheme for achieving maximal control over the system. Specifically, cooling and control of the nuclear environment of the Nitrogen Vacancy Centers in diamond leads to improved electronic coherence properties. In addition, it opens up the possibility of using the nuclear ensemble itself for quantum information applications.

**K1.00068** Classical Forces in Aharonov-Bohm Effects. SCOT MCGREGOR, ADAM CAPREZ, HERMAN BATELANA, University of Nebraska-Lincoln, RYAN HOTOVY, Texas A&M — Our recent experimental and theoretical work will be reported on Aharonov-Bohm type effects \(1\). This includes the experimental demonstration that the Matteucci-Pozzi phase shift is a result of a classical force \(2\); in contradiction to earlier claims that it is a Type-II Aharonov-Bohm effect \(3\). This result is part of a larger discussion that is centered around a classical paradox. Aharonov and Rohrlich point out that this paradox is “… crucial for clarifying the entirely quantum interactions of ‘fluxons’ and charges \(4\).” Surprisingly, the Lorentz force acting on an infinite solenoid in the presence of an approaching charge is neglected \(4\). Inclusion of the Lorentz force, along with the electromagnetic field momentum, leads to conservation of momentum. This motivates further investigation of the dual of the Aharonov-Bohm effect in which a neutral magnetic moment passes a charged wire. The question of sorting out which phase shifts are accompanied by classical force and which ones are not is still a topic of much debate and we report on our efforts to settle the argument.

\(^1\)We gratefully acknowledge support from NSF and DoE GAANN.

**K1.00069** Experimental Validation of Interferometry Simulations on an Atom Chip. VIOLETA PRIETO, JASON ALEXANDER, CHRISTOPHER ROWLETT, WILLIAM GOLDING, PATRICIA LEE, Sensors and Electron Devices Directorate, US Army Research Laboratory, Adelphi, MD — We report on recent experimental progress towards developing a compact atom interferometer on an atom chip using a double-well potential. The interferometer uses \(^{87}\)Rb atoms magnetically confined in an atomic waveguide produced by wires on the surface of a lithographically patterned chip. The double-well potential is created by dynamically changing the current configuration on our chip. We use combinations of different current configurations with various external bias fields that can offer the means to coherently split the atomic cloud through dynamically adjusting the currents and bias fields. We consider real-time transformations between different double-well configurations adiabatically and non-adiabatically, and study their effects on the initially trapped atoms.

**K1.00070** Atomic Test of the Equivalence Principle in a 10-meter Tower. SUSANNAH DICKERSON, JASON HOGAN, DAVID JOHNSON, ALEX SUGARBAKER, TIM KOVACHY, SHENG-WEY CHIOW, MARK KASEVICH, Stanford University — We aim to explore and expand the limits of atom interferometry at Stanford University. Atom interferometry uses the coherent splitting and recombination of atoms to make precision measurements of environmental parameters such as gravity, acceleration, or magnetic field. The apparatus has been designed to test Einstein’s Equivalence Principle to a precision of \(10^{-15}\)g by simultaneously launching ultracold atoms of different mass (specifically \(^{85}\)Rb and \(^{87}\)Rb) and accurately observing their free-fall motion in a vacuum chamber. Although we will perform the measurements with low-density clouds of cold atoms, we have demonstrated our ability to cool the atoms by forming Bose-Einstein condensates of \(^{87}\)Rb. Cold, dilute clouds can be launched with an optical lattice into the interferometer region. Splitting the atoms with Bragg pulses allows for the creation of a Mach-Zehnder interferometer for the Equivalence Principle measurement.

**K1.00071** Toward a sub-ppb measurement of α using atom interferometry with Bose-Einstein condensates. BEN PLOTKIN-SWINING, ALAN JAMISON, NATHAN KUTZ, SUBHADEEP GUPTA, University of Washington — We are preparing to perform an interferometric measurement of the recoil frequency of ytterbium atoms in a Bose-Einstein condensate (BEC). Such a measurement will yield a sub part-per-billion determination of the fine structure constant, α, and allow for stringent tests of QED. We present the design of our symmetric three-path BEC contrast interferometer, which is favorable for a precision measurement due to its insensitivity to vibrations and ac Stark shifts, and because the recoil phase varies quadratically with additional recoils. We choose Yb BECs as our atom source for its insensitivity to magnetic fields and its coherence properties. We discuss various possible sources of systematic error to our experiment, and our planned route to achieve sub-ppb precision. Mean-field effects are the largest potential source of systematic error. We present theoretical work that shows our ability to model these effects and subtract them from our final result. We report on current experimental progress, including diffraction of a Yb BEC using standing wave optical pulses — short pulses for momentum-state beam-splitting and long pulses as mirrors — as well as progress towards additional acceleration pulses in order to boost the recoil phase and achieve the desired precision.

\(^3\)This work is supported by NSF and NIST.

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\(^3\)We gratefully acknowledge support from NSF.
K.00072 Quantum random walks with multiphoton interference and high order correlation functions 1. BRYAN GARD, ROBERT CROSS, PETR ANISIMOVA, HWANG LEE, JONATHAN DOWLING, None, QUANTUM SCIENCES AND TECHNOLOGIES TEAM — We show a simulation of quantum random walks with distinct photon mixing in a system of 50/50 beam splitters with a bank of detectors at any desired level. We discuss the multiphoton interference effects that are inherent to this setup, and introduce one, two, and threefold coincidence detection schemes. The use of Feynman diagrams are used to intuitively explain the unique multiphoton interference effects of these quantum random walks.

1 AFOSR, FQXI, IARPA, and NSF

K.00073 Narrowband Source of Correlated Photon Pairs via Four-Wave Mixing in Atomic Vapour. BHARATH SIVATHSAN, GURPREET KAUR GULATI, MEI YUEN BRENDA CHNG, GLEB MASLENNIKOV, DZMITRY MATSUKEVICH, CHRISTIAN KURTSIEFER, Centre for Quantum Technologies, National University of Singapore — Many quantum communication protocols require entangled states of distant qubits which can be implemented using photons. To efficiently transfer entanglement from photons to stationary qubits such as atoms, one requires entangled photons with a frequency bandwidth matching the absorption profile of the atoms. In our setup, a cold Rb 87 atomic ensemble is pumped by two laser beams (780nm and 776nm) resonant with the S(1/2) → P(3/2) → D(5/2) transition. This generates time-correlated photon pairs (776nm and 795nm) by nondegenerate four-wave mixing via the decay path 5D(5/2) → 5P(3/2) → 5S(1/2). Coupling the photon pairs into single mode fibres and using silicon APDs, we observe g(2) of about 2000 and pairs to singles ratio of 11.2% (2800 photon pairs per second) with an optical bandwidth < 30/(2π) MHz.

K.00074 Heterodyne-based optical probe with sub-kHz resolution for coherent atomic media. RUSSELL MCLEAN, ALEXANDER AKULSHIN, Centre for Atom Optics and Ultrafast Spectroscopy, Swinburne University of Technology, Melbourne, Australia — We have demonstrated a coherent heterodyne technique for probing atomic media containing laser-induced coherence. Optical heterodyning with mutually coherent laser fields allows the detection of new spectral components generated by phase modulation and four wave mixing. The technique has sub-kHz resolution, well below the laser linewidth limit. We use two applied radiation fields tuned to particular transitions within the Rb D lines and separated by a small frequency offset, typically 100 kHz or less. To generate an enhanced atomic Kerr nonlinearity in a Rb vapour through the processes of coherent population trapping and coherent population oscillations. In the heterodyne technique, the transmitted fields, including the new fields resulting from these processes, are mixed with a reference field tuned beyond the region of enhanced nonlinear susceptibility, to generate beat signals observable on an RF spectrum analyzer. With a suitable choice of polarizations for the two applied fields the technique has allowed us to distinguish the processes responsible for generating the enhanced nonlinearity, and represents a novel approach to probing coherent atomic media that is complementary to the more commonly used probe-drive and Hanle-type methods.

K.00095 Power dependence of multi-photon processes in the S(1/2) → P(3/2) → D(5/2) transition of 87Rb atoms. HAN SEB MOON, HAN SEB MOON, Department of Physics, Pusan National University, HEUNG-RYOUNG NOH, Department of Physics, Chonnam National University — We have experimentally demonstrated the multi-photon effects of the ladder-type electromagnetically-induced transparency (EIT) according to the intensities of the probe and coupling lasers in the S(1/2) → P(3/2) → D(5/2) transition of 87Rb atoms. When the intensity of the probe laser was comparable to one of the coupling laser, the transmittance spectra of the S(1/2 → P(3/2) → D(5/2) transition were observed a variety of variation due to EIT and double-resonance optical pumping (DROP). The spectral features of the transmittance spectra were interpreted as the multi-photon processes composed of the one-photon resonance, the two-photon resonance, and the mixed term using the diagrammatic analysis of multi-photon processes. The observed transmittance spectra were a good agreement with the theoretically calculated results by the full density matrix equations.

K.00076 Spectrum and photon statistics of an optomechanical cavity QED system. ANDREW JACOBS, JAMES CLEMENS, Miami University — Work to date in cavity optomechanics has primarily focused on the coupling between the cavity field and the mechanical oscillator. We investigate a weakly driven, damped optomechanical cavity containing a two-level atom with an oscillating end mirror or an intracavity dielectric membrane. We carry out numerical simulations of the system using the framework of quantum trajectories implemented with the Quantum Toolbox in Python (QuTiP). We calculate the cavity probe spectrum and second-order field-field and atom-field correlations, finding they are modified by the coupling between the cavity field and the mechanical oscillator.

K.00077 Coherent optical excitations in superconducting qubit chain. HOU IAN, University of Macau, YU-XI LIU, Tsinghua University, Beijing, China — In the recent years, the theories of quantum optics have been borrowed to study the flows of electron pairs and their interactions with the circuit photon in the superconducting qubit circuits. These studies bring about new theories of quantum optics, such as the tunable electromagnetic transparency of the Cooper pairs in circuits. In this talk, we focus on a special type of superconducting qubit circuits: superconducting qubit chain (SQC), which comprises dozens of qubits linearly placed along a stripline resonator. Since the dimensions of the qubits and the stripline have made their interactions inhomogeneous, the SQC cannot be diagonalized using the usual Dicke model. We present a new theoretical method, the deformation-projection method, for the exact diagonalization of the collective excitations of the qubits. This method allows us to predict that these excitations emulate the behaviors of Wannier and Frenkel excitons in the solid-state systems. The spontaneous emissions from the individual qubits in SQC are relayed to their neighbors, eventually arriving at a coherent emission, known as superradiance. We present a quantum relay model, which is crucial to quantum information processing, based on this finding.

1 H.I. acknowledges support by University of Macau grant No. SRG003-FST12-III. Y.X.L acknowledges support by NNSFC grant no. 10975080 and 61025022.

K.00078 QUANTUM INFORMATION II —

K.00079 Fidelity analysis of a Rydberg blockade CNOT gate with simulated quantum process tomography. X.L. ZHANG, A.T. GILL, L. ISENHOWER, T.G. WALKER, M. SAFFMAN, University of Wisconsin — We present a detailed error analysis of a Rydberg blockade mediated controlled-NOT quantum gate between two neutral atoms. Numerical solutions of a master equation for the gate dynamics, including all known sources of technical error, are shown to be in good agreement with experiments. We also present numerical simulations of quantum process tomography to find the intrinsic fidelity, neglecting technical errors, of a Rydberg blockade controlled phase gate. The gate fidelity is characterized using trace overlap and trace distance measures. We show that the trace distance is linearly sensitive to errors arising from the finite Rydberg blockade shift and introduce a modified pulse sequence which corrects the linear errors. Error floors of O(10^{-3}) are found for 87Rb and Cs atoms.

1 This work was supported by the NSF, IARPA through ARO and DARPA.
Ensembles requires only the most natural process that occurs during stimulated emission. Classic capacity of noisy optical quantum channels was an open question and seemed to be completely impossible. We show that using photon-based encoder phenomenon is rooted in the extreme violation of additivity of the channel capacities of quantum channels. Recently, the most important discovery in quantum zero-capacity optical quantum channels makes it possible to use two zero-capacity optical quantum channels with a positive joint capacity for their output. The investi... a nearby Nitrogen Vacancy color center, we demonstrate high fidelity initialization and readout of a single 13C qubit. Quantum memory lifetime exceeding one second is obtained by using controlled dissipative optical decoupling from the electronic degree of freedom. Techniques to further extend the quantum memory lifetime as well as the potential applications are also discussed.

K1.00081 Multi-second quantum memory based upon a single nuclear spin in a room temperature solid. Peter Maurer, Georg Kucsko, Christian Latta, Harvard University, Liang Jiang, California Institute of Technology, Norman Yao, Steven Bennett, Harvard University, Fernando Pastawski, David Hunger, MPQ, Nick Chisholm, Harvard University, Mark Markham, Daniel Twitchen, Element 6, Ignacio Cirac. MPQ, Mikhail Lukin, Harvard University — Room temperature solid-state quantum bit with second-long memory Realization of stable quantum bits (qubits) that can be prepared and measured with high fidelity and that are capable of storing quantum information for long times exceeding second is an outstanding challenge in quantum science and engineering. Here we report on the realization of such a stable quantum bit using an individual 13C nuclear spin within an isotopically purified diamond crystal at room temperature. Using an electronic spin associated with a nearby Nitrogen Vacancy color center, we demonstrate high fidelity initialization and readout of a single 13C qubit. Quantum memory lifetime exceeding one second is obtained by using controlled dissipative optical decoupling from the electronic degree of freedom. Techniques to further extend the quantum memory lifetime as well as the potential applications are also discussed.

K1.00082 Enhanced solid-state multi-spin metrology using dynamical decoupling, Linh Pham, Harvard University, Nir Bar-Gill, Harvard University, Harvard-Smithsonian Center for Astrophysics, ChiinMay Beltangady, David LE SAGE, Harvard-Smithsonian Center for Astrophysics, Paola Cappelello, Massachusetts Institute of Technology, Mikhail Lukin, Amir Yacoby, Harvard University, Ronald Walsworth, Harvard University, Harvard-Smithsonian Center for Astrophysics — We use multi-pulse dynamical decoupling to increase the coherence lifetime (T2) of large numbers of nitrogen-vacancy (NV) electronic spins in room temperature diamond, thus enabling scalable applications of multi-spin quantum information processing and metrology. We realize an order-of-magnitude extension of the NV multi-spin T2 for diamond samples with widely differing spin environments. For samples with nitrogen impurity concentration \( > 1 \) ppm, we find T2 \( > 2 \) ms, comparable to the longest coherence time reported for single NV centers, and demonstrate a ten-fold enhancement in NV multi-spin sensitivity of AC magnetic fields.

K1.00083 Classical Communication with Stimulated Emission over Zero-Capacity Optical Quantum Channels1, Laszlo Gyongyosi, Sandor Imre, Budapest University of Technology and Economics — The superactivation of zero-capacity optical quantum channels makes it possible to use two zero-capacity optical quantum channels with a positive joint capacity for their output. The phenomenon is rooted in the extreme violation of additivity of the channel capacities of quantum channels. Recently, the most important discovery in quantum information theory was the possibility of transmitting quantum information over zero-capacity quantum channels. Before our work, the superactivation of the classical capacity of noisy optical quantum channels was an open question and seemed to be completely impossible. We show that using photon-based encoder and decoder setting, classical information can also be transmitted over the combination of zero-capacity optical quantum channels. The proposed scheme requires only the most natural process that occurs during stimulated emission.

The results discussed above are supported by the grant TAMOP-4.2.2.B-10/1-2010-0009 and COST Action MP1006.

K1.00084 Long Distance Quantum Communication Using Cascade Emission in Atomic Ensembles1, Hsiang-Hua Jen, National Tsing Hua University — The ladder configuration of atomic levels provides a source for telecom photons (signal) from the upper atomic transition. For rubidium and cesium atoms, the signal field has the range around 1.3-1.5 \( \mu \text{m} \) that can be coupled to an optical fiber and transmitted to a remote location. Cascade emission may result in pairs of photons, the signal entangled with the subsequently emitted infrared photon (idler) from the lower atomic transition. This correlated two-photon source is potentially useful in the DLZC protocol for the quantum repeater. We investigate the two-atom cascade emission fidelities and potential applications in the DLZC protocol and find that it deteriorates the performance but the harmful effect can be diminished by using shorter pump pulses to generate the cascade emission.

1 NSF, USA and NSC, Taiwan, ROC.

K1.00085 Trapped-ion Quantum Information Processing using Scalable Techniques1, Ryan Fowler, John Gaebler, YiHeng Lin, Ting Rei Tan, National Institute of Standards and Technology, David Hanneke, Amherst College, John Jost, National Institute of Standards and Technology, Jonathan Home, ETH Zurich, Adam Meier, Emmanuelle Knill, Dietrich Leibfried, David Wineland, National Institute of Standards and Technology — We report progress towards combining all the building blocks required for scalable quantum information processing using trapped atomic ions. Included elements are qubits with long coherence times, a laser-induced universal gate, motional state initialization using a second ion species, and information transport. We currently explore techniques to efficiently measure gate fidelity in a scalable way involving multiple qubits and randomized benchmarking. For this, we perform sets of quantum information sequences involving as many as 16 two-qubit entanglement gates and 50 single-qubit gates. We have also developed an arbitrary waveform generator with an update rate far above the ions’ motional frequencies which is capable of rapidly bringing together and separating the qubit ions each time a two-qubit gate is performed.

1 Supported by IARPA, NSA, ONR, DARPA & the NIST Quantum Information Program.

K1.00086 Progress towards a polarization spectroscopy experiment for quantum control of collective spin, Pascal G. Mickelson, Enrique Montano, Daniel Hemmer, Paul S. Jessen, University of Arizona — We report preliminary results from an experiment that will implement quantum control of the collective spin of an atomic ensemble. In our setup, a weak probe laser interacts with a cold, trapped atomic sample of cesium atoms with high optical depth, leading to Faraday rotation of the probe light proportional to the atomic magnetization. If the atom-light coupling is strong enough, polarimetry of the probe light will provide a measurement of the magnetization with resolution better than the spin projection noise, at which point measurement back-action will become significant enough to be used for quantum control of the spin. Thus far, we have loaded cesium atoms into a \(~50\ \mu\text{m}\) deep optical dipole trap, and we observe Faraday rotation of the probe light as it passes through this cloud of atoms. Work is ongoing to increase the optical depth of the atom sample and to optimize the atom-light coupling by mode-matching the probe beam to the atom sample.
of the fermionic molecules from remaining atoms in a magnetic field gradient. We will also discuss the possibility of molecule formation in an optical lattice as well as features shaped to minimize time spent near resonance while maintaining adiabaticity, and an improved optical trapping geometry that gives faster separation of formed and closed channel states occurs in a region less than 50 mG wide. Our experimental configuration includes one part per 10^5 atoms from a magneto optical trap as well as CO ionize the Rydberg atoms. DC voltages are applied on the other grids, which work as electrostatic lenses. By varying such voltages, we are able to get a better neutrality of molecular ions. Since this approach relies on cooling rotational and vibrational quanta by exciting an electronic transition, it is most straightforward at cold Rydberg atoms. In contrast to other experiments producing cold molecular ions, our proposed method efficiently cools both the internal and external freedom of molecular ions. This work is supported by AFOSR and NSF.

K1.00088 COLD ATOMS, MOLECULES, AND PLASMAS II –

K1.00089 Experiments on the Verification of the 1-D Tan Relations for Bosons in an Atom Chip Waveguide , JASON ALEXANDER, VIOLETA PRIETO, CHRISTOPHER ROWLETT, PATRICIA LEE, WILLIAM GOLDING, Sensors and Electronic Devices Division, U.S. Army Research Laboratory, Adelphi, MD — Recently it has been shown that a single quantity called the “contact” characterizes the behavior of interacting fermions at short distances. A set of universal relations was developed connecting the contact to the long range, thermodynamic properties of a gas of fermions. Some of these relations have been verified experimentally for fermions and bosons in three dimensions. As a result there has been a great deal of theoretical interest in this area and similar relations have been developed for bosons in 1-D. In this work, we continue to report results on the experimental verification of some of these 1-D relations for a system of bosons (87Rb) confined to the (quasi) 1-D potential of an atom chip magnetic waveguide. We measure the contact via the momentum distribution for various inter-particle interaction strengths. We discuss how the contact can serve as a marker for the phase transitions between the thermal gas, the Bose-Einstein condensate, and the Tonks-Girardeau gas. Previously, we reported very preliminary results for a 1-D thermal gas. Here we report measurements of the contact for a 1-D condensate and discuss progress towards observing the transition to the Tonks-Girardeau regime for atoms in our atom chip waveguide.

K1.00090 Expansion dynamics of a non-spherical ultracold plasma in a supersonic molecular beam , MARKUS SCHULZ-WEILING, ED GRANT, University of British Columbia — Molecular beam plasma dynamics are subject to a superposition of the residual molecular beam expansion of the laser illuminated excitation volume with ambipolar expansion owing to charged particle many-body interactions. We combine beam calculations with a consideration of the excitation processes that lead to plasma formation to determine the initial phase space distribution function of our plasma particles. Subsequent application of kinetic theory yields a model for the evolution of our system. By solving Vlasov’s equation for our initial conditions, we obtain a first-order approximation for ambipolar expansion in the geometry of our system.

K1.00091 Molecule Formation Experiments with Ultracold Gases of 23Na and 6Li , TOUT T. WANG, Department of Physics, Harvard University, MYOUNG-SUN HEO, TIMUR M. RVACHOV, WOLFGANG KETTERLE, DAVID E. PRITCHARD, Research Laboratory for Electronics, Department of Physics, MIT — We will describe progress towards making Feshbach molecules from an ultracold mixture of 23Na and 6Li. Molecule formation attempts were done around a closed-channel dominated Feshbach resonance at 796 G, for which significant coupling between open and closed channel states occurs in a region less than 50 mG wide. Our experimental configuration includes one part per 10^5 magnetic field stability, field ramps shaped to minimize time spent near resonance while maintaining adiabaticity, and an improved optical trapping geometry that gives faster separation of formed molecules from remaining atoms in a magnetic field gradient. We will also discuss the possibility of molecule formation in an optical lattice as well as features of the fermionic 23Na6Li molecule in its ro-vibrational ground state.

K1.00092 Characterization of an imaging system for cold Rydberg atoms , JADER CABRAL, JORGE KONDO, LUIS GONCALVES, LUIS MARCASSA, University of São Paulo — In this work, we have built an imaging system for cold Rydberg atoms. The system consists of three grids, a tube of flight and a MCP (micro channel plates) detector with a phosphor screen. In one of the grid, we can apply a HV pulse to ionize the Rydberg atoms. DC voltages are applied on the other grids, which work as electrostatic lenses. By varying such voltages, we are able to get a better resolution in our MCP detector. The ions are detected by the MCP, with image them on the phosphor screen. We have obtained ion images of cold Rydberg atoms from a magneto optical trap as well as CO2 dipole trap. The experimental images were compared with theoretical images obtained from a simulation, and a good agreement was observed.

K1.00093 Towards production of ultracold molecular ions in a hybrid trap system , SCOTT SULLIVAN, WADE RELLERGERT, RUANG CHEN, STEVEN SCHOWALTER, University of California, Los Angeles, SVETLANA KOTOCHIGOVA, Temple University, ERIC HUDSON, University of California, Los Angeles — We describe a new method for the production of ultracold molecular ions. This method utilizes sympathetic cooling due to the strong collisions between appropriately chosen molecular ions and laser-cooled neutral atoms to realize ultracold, internal ground-state molecular ions. In contrast to other experiments producing cold molecular ions, our proposed method efficiently cools both the internal and external molecular ion degrees of freedom. The availability of truly ultracold molecular ions will impact fields as diverse as quantum chemistry, precision measurement, and quantum information/computation. We present preliminary results towards demonstration of rovibrational relaxation in BaCl.

K1.00094 Optical pulse-shaping for internal cooling of molecules , CHIEN-YU LIEN, CHRIS SECK, SCOTT WILLIAMS, BRIAN ODOM, Northwestern University — We propose a scheme to use pulse-shaped femtosecond lasers to optically cool the internal degrees of freedom of molecular ions. Since this approach relies on cooling rotational and vibrational quanta by exciting an electronic transition, it is most straightforward for molecular ions with diagonal Frank-Condon-Factors. Compared with schemes that cool rotations by exciting vibrations, this approach achieves internal cooling on the orders-of-magnitude faster electronic decay timescale and is potentially applicable to apolar molecules. For AIH , a candidate species, a rate-equation simulation shows that rovibrational equilibrium should be achievable in 8 µs. Progress towards the experimental realization of this scheme for rovibrational optical cooling AIH , including the molecular ion production technique, details of the optical pulse shaping, and the state readout scheme will be discussed.

*1* This work is supported by AFOSR and NSF.
K1.00095 Achieving higher Gamma plasmas using higher ionization states

This project is funded by NSF Grant Number PHY-0969856.

K1.00096 Few-body interactions in ultracold gases

Recent experiments show that few-body interactions exist in ultracold gases. In this presentation, one-body, two-body, three-body, and four-body interactions will be illustrated. The results reported here provide useful information for gas to condensed phase transitions, and may be used for quantum information, high precision spectroscopy, as well as few-body entanglements.

K1.00097 Collective Modes of Spin-Orbit Coupled Condensate

ZHU CHEN, HUI ZHAI, Institute for Advanced Study, Tsinghua University — Collective modes of spin-orbit coupled Bose-Einstein condensate in harmonic potential are studied systematically. The NIST type spin-orbit coupling is considered mainly due to its experimental realization. The dipole oscillation frequency turns out to be related to the oscillation magnitude, which is the reflection of the the violation of kohn’s theorem. Analytical results are obtained in small amplitude limit, which are consistent with the effective mass theory. Breath modes and surface modes are also obtained, which are shown to be coupled with the center of mass motion. Mode resonance among them is observed. Furthermore, a special case is considered when center of mass motion in real space induces tunneling in momentum space. A simplified two-mode model is proposed to explain qualitatively such oscillation plus tunneling process. At last, the most general form of spin-orbit coupling is studied, and results in small amplitude limit are also obtained.

K1.00098 From Anderson to Anomalous Localization in Cold Atomic Gases with Effective Spin-Orbit Coupling

JOHANNES OTTERBACH, Harvard University, Cambridge, MA, USA, MATTHEW EDMONDS, Heriot-Watt University, Edinburgh, UK, MIKHAIL TITOV, Karlsruhe Institute of Technology, Karlsruhe, Germany, Heriot-Watt University, Edinburgh, UK, PATRICK ÖHBERG, Heriot-Watt University, Edinburgh, UK, RAZMIK UNANYAN, MICHAEL FLEISCHHAUER, TU Kaiserslautern, Kaiserslautern, Germany — The advanced techniques in coherently controlling and manipulating cold atomic gases allow for the formation of, e.g., artificial magnetic fields or the creation of effective Spin-Orbit coupling for neutral atoms. Confining such spin-orbit coupled particles to one dimension gives rise to an effective relativistic Dirac-like dynamics in the limit of small particle momenta. The addition of disorder potentials drastically changes the properties of these systems giving rise to phenomena as, e.g., exponential Anderson localization. Here we study the dynamics of ultracold atoms with an effective Spin-Orbit coupling moving in a one-dimensional random potential. We show that tunning the ratio between spin-orbit coupling and disorder strength leads to a crossover from exponential Anderson-like localization of massive particles to an anomalous power-law behavior. Its origin can be traced back to the emergence of a Dyson-like singularity in the density of states around the zero-energy (mid-gap) state, reminiscent of the so-called Random Mass Dirac model.

K1.00099 Chaotic dynamics of dipolar condensates in optical traps

ROXANNE MORAN, BOAZ ILAN, KEVIN MITCHELL, University of California, Merced — The potential energy of two-dimensional optical traps typically induces chaotic dynamics in the resulting classical trajectories. This has a profound impact on the transport and escape properties of ultracold atoms in such traps. Prior theory showed that attractive atomic contact interactions would enhance the relative importance of classical fractal structures in the quantum chaotic scattering, by reducing quantum dispersion. With recent experimental advances in creating degenerate dipolar gases, we seek to understand the relevance of long-range dipole-dipole interactions on the chaotic scattering and transport rates of gases in optical potentials. Given the theoretical predictions of two-dimensional solitons in such gases, we expect a correspondingly large enhancement in the role of classical fractal structures.

K1.00100 Nonlinear dynamics and solitonic structures of two-component BECs

JIAJIA CHANG, PETER ENGELS, Washington State University — We present ongoing experimental studies of the rich nonlinear dynamics of two-component $^{87}$Rb BECs. These dynamics range from counterflow induced modulational instabilities to the formation of spin domains and novel solitonic structures, including soliton clusters. We report on the current status of the experiment.

K1.00101 Experiments with Quantum Degenerate Atomic Strontium

MI YAN, BRIAN DESALVO, YING HUANG, RAMACHAND BALASUBRAMANIAN, HAN PU, THOMAS KILLIAN, Rice University — We will describe experiments with quantum degenerate gases of atomic strontium. We are able to produce Bose-Einstein condensates of $^{84}$Sr and quantum degenerate mixtures of $^{87}$Sr (fermion) and $^{86}$Sr (boson). With $^{86}$Sr we have demonstrated control over condensate dynamics with an optical Feshbach resonance and have developed tools to model the dynamics after a rapid change in scattering length. We will describe photoasssociative spectroscopy near the $^1S_0-^3P_1$ atomic asymptote for various isotopes and the calculation of parameters for optical Feshbach resonances. We will also discuss our recent progress loading condensates into optical lattices.

K1.00102 Thermodynamics of the two-component Fermi gas with unequal masses at unitarity

This work was supported by the National Science Foundation and the Welch Foundation.

K1.00103 Thermodynamics of the two-component Fermi gas with unequal masses at unitarity

We consider mass-imbalanced two-component Fermi gases for which the unequal-mass atoms interact via a zero-range model potential with a diverging s-wave scattering length $a_s$, i.e., with $1/a_s = 0$. The high temperature thermodynamics of the harmonically trapped and homogeneous systems are examined using a virial expansion approach up to third order in the fugacity. We find that the universal part of the third-order virial coefficient associated with two light atoms and one heavy atom is negative, while that associated with two heavy and one light atom changes sign from negative to positive as the mass ratio $\kappa$ increases, and diverges when Efimov physics sets in at $\kappa = 13.61$. By examining the Helmholtz free energy, we find that the equilibrium polarization of the trapped and homogeneous systems is 0 for $\kappa = 1$, but finite for $\kappa \neq 1$ (with a majority of heavy particles). Compared to the equilibrium polarization of the non-interacting system, the equilibrium polarization at unitarity is increased for the trapped system and decreased for the homogeneous system. We find that unequal-mass Fermi gases are stable for all polarizations.

We gratefully acknowledge support by the NSF.
K1.00103 Two-dimensional Fermi gases. ENRICO VOGT, MICHAEL FELD, BERND FRÖHLICH, DANIEL PERTOT, MARKO KOSCHORRECK, MICHAEL KÖHL, University of Cambridge, UK — We report on our latest investigations on two-dimensional Fermi gases. We present the studies on collective excitations of a harmonically trapped two-dimensional Fermi gas from the collisionless to the hydrodynamic regime in order to investigate scale invariance and viscosity. We additionally investigate balanced and imbalanced Fermi mixtures in optical lattices using momentum-resolved photoemission spectroscopy. Those measurements include the observation of a many-body pairing gap above the superfluid transition temperature in a harmonically trapped, two-dimensional atomic Fermi gas in the regime of strong coupling. Furthermore we report the creation and experimental investigation of both attractive and repulsive Fermi polaron quasiparticles in two dimensions, which result when a small number of spin-down $^{40}$K atoms are immersed in a two-dimensional Fermi sea of spin-up $^{40}$K atoms. The single-particle spectral function $A(k, E)$ of the Fermi polarons, which directly reveals the quasi-particle properties like the energy and effective mass, is measured giving access to the full (momentum-resolved) quasiparticle dispersion.

K1.00104 A new strongly interacting Bose-Fermi mixture of $^{23}$Na and $^{40}$K. CHENG-HSUN WU, IBON SANTIAGO, JEE WOO PARK, PEYMAN AHMADI, SEBASTIAN WILL, MARTIN ZWIERLEIN, Massachusetts Institute of Technology — We have created a quantum degenerate Bose-Fermi mixture of $^{23}$Na and $^{40}$K with widely tunable interactions via broad interspecies Feshbach resonances. Over thirty Feshbach resonances between $^{23}$Na and $^{40}$K were identified, including $p$-wave multiplet resonances. Observed broad Feshbach resonances opens up a path to study the fate of an impurity interacting with its environment, a fundamental problem in condensed matter physics. We study the interaction of an impurity immersed in a Bose-Einstein condensate of $^{23}$Na. We perform radio-frequency spectroscopy on the impurity atom and the bath, which is expected to probe the spectral features characteristic for polaronic dressing. A delta-like peak in addition to a broad pedestal coming from the interactions between the impurity and the phonons in the condensate. Our system, with its widely tunable interactions, promises to be an ideal system to study the evolution from Bose polarons to Fermi polarons as the imbalance between $^{23}$Na and $^{40}$K is varied.

1Work was supported by the NSF, AFOSR-MURI and -PECASE, ARO-MURI, ONR YIP, DARPA YFA, a grant from the Army Research Office with funding from the DARPA OLE program and the David and Lucille Packard Foundation.

K1.00105 Ultracold Molecules in Lattices for Metrology and Precision Measurements. GAEL REINAUDI, CHRIS OSBORN, MICKEY MCDONALD, DILI WANG, TANYA ZELEVINSKY, Columbia University — Ultracold diatomic molecules offer exciting possibilities for studies of novel states of matter, quantum information, and metrology. Two-electron-atom based molecules are particularly promising for precision measurements, such as molecular time metrology and variations of the proton-electron mass ratio. We present an experimental setup that allows for the photodissociation, in an optical lattice, of strontium atoms into molecules using the narrow singlet-triplet transitions. We feature newly observed two-photon photodissociation to deeply bound molecular levels, as well as the study of the lifetime of such molecules in lattices, which is a determining factor concerning the practical use of this system. Other characteristics of our setup are presented, such as a computer controlled permanent-magnet Zeeman slower optimized with a genetic algorithm.

K1.00106 Stable blue detuned trap arrays for multi-qubit quantum gate experiments. MICHAL PIOTROWICZ, KARA MALLER, MARTY LICHTMAN, SIYUAN ZHANG, GANG LI, LARRY ISENHOWER, MARK SAFFMAN, University of Wisconsin — We have implemented a new approach to trapping single atom qubits using an array of blue detuned Gaussian laser beams which overlap weakly. This creates a two-dimensional array of 3D trap sites that are spatially stable, and are insensitive to phase drifts due to wavelength scale motion of the optical elements used for beam projection. A combination of diffractive and refractive optics is used to generate the beam array with high efficiency. We report on progress towards trapping and quantum state control of single Cs atoms in the array.

1This work was supported by IARPA through ARO, and DARPA.

K1.00107 Ultracold Fermions in an Optical Lattice with Tunable Geometry. GREGOR JOTZU, LETICIA TARRUELL, DANIEL GREIF, THOMAS UEHLINGER, TILMAN ESSLINGER, Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland — Ultracold Fermi gases in optical lattices have emerged as a versatile tool to simulate condensed matter phenomena. We present an optical lattice whose potential can be dynamically deformed to take on square, triangular, honeycomb, dimer and different one-dimensional geometries. Using Bloch-Oscillations of a Fermi gas, we probe the bandstructure of this lattice for various configurations. In particular, we observe the appearance of Dirac points with tunable properties. When introducing a lattice anisotropy, two Dirac points approach each other and eventually annihilate. A band-gap can be created at the Dirac points by continuously breaking the inversion symmetry of the system. Furthermore, we study how the effects of interactions change depending on the geometry of the lattice. We report on recent progress on using the dynamic tunability of the lattice as a method to study spin correlations in the system.

K1.00108 Laser Spectroscopy of Rydberg Atoms in Deep Optical Lattices. YUN-JIHH CHEN, GEORG RAITHEL, The University of Michigan — We are constructing a new setup to investigate the spectroscopic studies of Rydberg atoms inside a deep optical lattice. Instead of counter-propagating laser beams, the new setup uses an optical resonator to produce the lattice. A 1064 nm lattice laser is focused at the center of a concentric cavity, which is composed of two spherical mirrors with high reflectivity. The laser intensity inside the cavity can be enhanced hundreds of times, so an optical lattice of 10 GHz deep can be realized with fairly low laser input. With the lattice depth in the GHz regime, we expect to see the rich spectroscopy. Those measurements include the observation of a many-body pairing gap above the superfluid transition temperature in a harmonically trapped, two-dimensional Fermi gas.

1We acknowledge support from NSF.

K1.00109 Proposal to frustrated spin model in optical lattices. YANGHOO CHAN, EMILY LICHKO, LUMING DUAN, Physics Department, University of Michigan — We propose a setup to generate next-nearest neighbor hoppings with the amplitude comparable to nearest neighbor hoppings in optical lattices. The effective model can be described as a frustrated spin model. We also study the phase diagram with the recently developed tensor network algorithm based on infinite projected entangled pair states (iPEPS). The simulation indicates a promising spin liquid phase in a finite parameter region, where magnetic of valence bond solid order vanish.

K1.00110 A Next Generation Machine for Fermions in Optical Lattices Experiments. WUIK HUANG, AVIV KESHET, EDWARD SU, CHRISTIAN SANNER, JONATHON GILLEN, WOLFGANG KETTERLE, Massachusetts Institute of Technology — We are building a new $^{23}$Na-$^{40}$K machine for optical lattices experiments. Major experimental setups and upgrades will be described in details. We will also discuss how to reach the antiferromagnet regime and study quantum magnetism.
K1.00111 Progress toward observation of AFM ordering of ultracold fermions in an optical lattice\textsuperscript{1}, RUSSELL A. HART, PEDRO M. DUARTE, TSUNG-LIN YANG, RANDALL G. HULET, Rice University — We present progress toward the observation of antiferromagnetic (AFM) ordering of fermionic atoms in an optical lattice. We first laser cool on the $2\Sigma_{1/2} \rightarrow 2\Pi_{3/2}$ transition and then further cool using the narrow $2\Sigma_{1/2} \rightarrow 3\Pi_{1/2}$ transition to $T \sim 59 \mu K$\textsuperscript{2}. The second stage of laser cooling greatly enhances loading to an optical dipole trap where a two spin state mixture of atoms is evaporatively cooled to degeneracy. We then adiabatically load $\sim 10^6$ degenerate fermions into a 3D optical lattice formed by three orthogonal standing waves of $1064$ nm light. Each of the three lattice beams is overlapped with a non-retroreflected green beam at $532$ nm, which offsets the harmonic trapping caused by the lattice light. This offset can extend the number of lattice sites over which a Mott insulator phase can exist and facilitates evaporative cooling in the lattice. By adjusting the $s$-wave scattering length and the depth of the lattice, we tune the interaction and hopping terms of the Hubbard Hamiltonian. We will use Bragg scattering of light off of ordered spin planes to detect the AFM state\textsuperscript{3}.

\textsuperscript{1}Supported by NSF, ONR, DARPA, and the Welch Foundation.


K1.00112 Generating strong artificial magnetic fields, spin-orbit coupling, and non-abelian gauge fields with few lasers, KADEN HAZZARD, JILA, NIST, University of Colorado-Boulder, ERICH MUELLER, Laboratory of Atomic and Solid State Physics, ANA MARIA REY, JILA, NIST, University of Colorado-Boulder — We propose an experimental scheme to generate strong gauge fields for atoms in an optical lattice, up to unit flux per plaquette, requiring fewer lasers than other proposals\textsuperscript{1,2,3}. Like similar proposals\textsuperscript{1,2}, one generates a state-dependent lattice and couples adjacent sites with laser-induced tunneling. Our scheme, however, rectifies the resulting staggered magnetic flux to a homogeneous field using (experimentally feasible) “stroboscopic” time-dependent manipulation of the lattice lasers. One can generate sufficiently strong effective magnetic fields $|U(1)$ gauge fields$|$ to, for example, explore the interplay of fractional quantum Hall and lattice physics. For the case of alkaline earth atoms, the technique extends to generate SU(N) gauge fields, which are even richer. For example, simple homogeneous SU(2) gauge fields can be equivalent to spin-orbit coupling, which can host topological insulating phases even without interactions.

\textsuperscript{1}D. Jaksch and P. Zoller, NJP \textbf{5}, 56 (2003).

\textsuperscript{2}E. Gerbier and J. Dalibard, NJP \textbf{12} 033007 (2010).

\textsuperscript{3}N. Cooper, PRL \textbf{106}, 175301 (2011).

K1.00113 Single-site resolved studies of a bilayer quantum degenerate gas, RUICHAO MA, PHILIPP PREISS, MING TAI, Harvard University, WASEEM BAKR, Massachusetts Institute of Technology, JONATHAN SIMON, MARKUS GREINER, Harvard University — Ultracold atoms in optical lattices are a versatile platform for quantum many-body simulation with the promise of insights into quantum magnetism, superconductivity, and superfluidity. In recent years, quantum gas microscopes with single-site resolution have opened the door to local observation and manipulation of strongly correlated two-dimensional quantum gases. Here we present techniques for extending study to two tunnel-coupled planes. Using an axial superlattice we prepare a bilayer system, with full control of the inter-plane tunnel coupling and detuning. We observe coherent inter-plane population transfer with single-site resolution in both planes. A collisional energy blockade in the bilayer system allows us to go beyond parity imaging and unambiguously identify site occupations from zero to three atoms. We have obtained site-resolved images of the “wedding-cake” Mott insulator structure and antiferromagnetic ordering in a quantum Ising model. Further applications include spin-dependent readout and in situ phase imaging.

K1.00114 Dynamics of a Quasi-1D Bose Condensate in a Double Well Potential Intermediate Between the Tonks-Girardeau (TG) and Gross-Pitaevskii Regimes\textsuperscript{1}, T. BERGEMAN, SUNY Stony Brook, ZHENG ZHANG, SUNY Stonybrook — Dunjko et al.\textsuperscript{1} have shown how results of Lieb and Liniger\textsuperscript{2} can be used to calculate the ground state of 1D bosons in a harmonic trap, for densities varying between the TG and GP regimes. Berman et al.\textsuperscript{3} have shown that dramatic effects in the entropy occur in the transition between these regimes. As we are not aware of predictions for the dynamical behavior of quasi-1D Bose ensembles in double well potentials, we are attempting to adapt approaches of\textsuperscript{4} to model oscillations through a barrier of varying height. Simple time-dependent GP equations reveal damping, but what happens at low density is not yet known.

\textsuperscript{1}V. Dunjko, V. Lorent, and M. Olshanii, PRL \textbf{86}, 5413 (2001).


\textsuperscript{3}G. P. Berman et al., PRL \textbf{92}, 030404 (2004).


\textsuperscript{1}Supported by US NSF.

K1.00115 Supersmectic, Superglass, and Spin-Glass Phases in Multimode cQED, ALICIA KOLLAR, ALEXANDER PAPAGEORGE, Stanford University, SARANG GOPALAKRISHNAN, University of Illinois at Urbana-Champaign, PAUL GOLDBART, Georgia Institute of Technology, BENJAMIN LEV, Stanford University — Investigations of many-body physics in an AMO context often employ a static optical lattice to create a periodic potential. Such systems, while capable of exploring, e.g., the Hubbard model, lack the fully emergent crystalline order found in solid state systems whose stiffness is not imposed externally, but arises dynamically. We propose an experiment to explore the spontaneous continuous symmetry breaking observed in compliant crystals, and we aim to create an environment for the observation of effects pertinent to soft condensed matter systems including frustration and liquid crystalline topological defects concomitant with superfluidity. Off-resonantly pumping a BEC confined in a multimode cavity can induce a quantum version of the Brazovskii transition that arises in soft (classical) condensed matter contexts. The resultant supersmectic phase of intracavity atoms may suffer from sufficient global frustration to allow the formation of a superglass. Spin-glasses may also form due to cavity-mediated long-range, oscillatory, and frustrated spin-spin interactions.

K1.00116 Quantum Dynamics of Solitons in Strongly Interacting Systems on Optical Lattices, CHESTER RUBBO, JILA, RADHA BALAKRISHNAN, The Institute of Mathematical Sciences. WILLIAM REINHARDT, University of Washington, Seattle, INDEBALA SATIJA, Joint Quantum Institute, NIST; ANA REY, SALVATORE MANMANA, JILA — We present results of the quantum dynamics of solitons in XXZ spin-$1/2$ systems which in general can be derived from a system of spinless fermions or hard-core bosons (HCB) with nearest neighbor interaction on a lattice. A mean-field treatment using spin-coherent states revealed analytic solutions of both bright and dark solitons\textsuperscript{1}. We take these solutions and apply a full quantum evolution using the adaptive time-dependent density matrix renormalization group method (adaptive t-DMRG), which takes into account the effect of strong correlations. We use local spin observables, correlations functions, and entanglement entropies as measures for the stability of these soliton solutions over the simulation times.

K1.00117 Few-body ultracold reactions in a Bose-Fermi mixtures. CHEN ZHANG, JAVIER VON STECHER, CHRIS H. GREENE, JILA and Physics Department, University of Colorado at Boulder — This project investigates the properties of fermionic molecule $^{87}\text{Rb}^{40}\text{K}$, including (i) its formation from a mixed gas of bosonic $^{87}\text{Rb}$ and fermionic $^{40}\text{K}$ through magnetic field ramping and (ii) its scattering properties after formation. This has been approached mainly from the few body perspective: the spectrum of two bosons($^{87}\text{Rb}$) and two fermions($^{40}\text{K}$) is first calculated in a harmonic trap using correlated-Gaussian basis throughout the range of a broad Fano-Feshbach resonance. This provides a few-body solution to the magneto-association of fermionic Feshbach molecules, subsequently used to study the time-evolution of the system as the scattering length changes, mimicking experiments with Bose-Fermi mixture near Fano-Feshbach resonances. The structure of avoided crossings in the few-body spectrum enables an interpretation of the dynamics of the system as a sequence of Landau-Zener transitions. The calculated molecule formation rate is compared with experimental observations. Molecule-atom and molecule-molecule scattering properties are also discussed.

1NSF

K1.00118 Photoassociation of Rb atoms in an optical dipole trap. CARLOS MENEGATTI, BRUNO MARANGONI, University of Sao Paulo, NADIA BOULOUFA, OLIVIER DULIEU, Laboratoire Aim Cotton, Universit Paris-Sud, LUIS MARCASSA, University of Sao Paulo — Laser cooling and trapping techniques are nowadays routinely used to produce atomic samples at temperatures around 1 mK or below. An old ambition in this research field is the direct application of such techniques to molecules, however due to the absence of closed optical transitions in molecules this is not straightforward. Nevertheless, cold and dense atomic trapped samples can be used to produce cold molecules trough photoassociation. In our experiment, we have trapped Rb atoms in a crossed broadband optical dipole trap. Our crossed beam configuration uses 25 W of power (at 1064 n, bandwidth of 2 nm) in each beam with about 50 micron waist radius at the focus and a depth of about 700 $\mu$K. In the typical condition, we have about 3 x 10^12 trapped atoms at a density of 3 x 10^12 cm^-3. We have observed that the Rb atom population presents a non-exponential decay in such a trap. We believe that such observation suggests that the sample is been photoassociated by the 1064 nm laser, forming an excited state Rb$\text{v}$ molecule, which further decays forming Rb$\text{b}$ in the ground state. The results are compared with a theoretical model.

1We acknowledge financial support from FAPESP, CNPq, INCT-IQ.

K1.00119 Photoassociative Spectroscopy of the (2)$^3\Pi$ State in RbCs. COLIN BRUZEWICZ, MATTIAS GUSTAVSSON, TOSHIIKO SHIMASAKI, DAVID DEMILLE, Yale University — We photoassociate RbCs molecules into several deeply-bound vibrational levels of the $\Omega = 0$ and $\Omega = -1$ components of the (2)$^3\Pi$ state. These include both previously observed and newly discovered levels. We measure the photoassociation laser intensity dependence of ground state molecule production for these levels and compare the saturation behavior to theoretical predictions. Using RKR analysis of the relevant molecular potentials, we have predicted and located a photoassociation state ((2)$^3\Pi_0$, $v = 10$, $J = 1$) that decays favorably to the $v = 0$ vibrational level of the ground $X^1\Sigma^+$ state. This presents a promising pathway to the production of large numbers of rovibrational ground state polar molecules.

K1.00120 Observation of Blue-Detuned Photoassociation to the 2 (0$^+_g$) State of $^{85}\text{Rb}_2$ via REMPI. MICHAEL BELLOS, RYAN CAROLLO, DAVID RAHMLOW, JAYITA BANERJEE, MATTHEW BERNADEZ, EDWARD EYLER, PHILLIP GOULD, WILLIAM STWALLEY, University of Connecticut — We report detection of photoassociation to vibrational levels blue of the $^{85}\text{Rb}_2$: 5$s$ + 5$p_{1/2}$ asymptote, in the previously-unobserved 2 (0$^+_g$) Hund’s case (c) state that corresponds to 2 $^1\Sigma^+_g$ in Hund’s case (a). These excited-state ultracold molecules decay to the $a^1\Sigma^+_u$ state and are detected by pulsed REMPI through the 2 $^3\Sigma^+_g$ state. We also observe, via trap loss, the 2 (0$^+_g$), 2 (0$^+_g$), and 2 (1$^+_g$) states observed in [1], and confirm that these states are not the source of the observed molecules. Photoassociation through the observed levels of the 2 (0$^+_g$) state populates vibrational levels approximately halfway up the $a^1\Sigma^+_u$ potential well. This pathway complements the blue-detuned photoassociation technique described in [2], which accesses the bottom of the $a$ state potential.


This work is supported by the NSF and AFOSR.

K1.00121 Quantum Mixtures of Ultracold Lithium and Ytterbium Atoms. ALEXANDER KHRAMOV, ANDERS HANSEN, WILLIAM DOWD, ALAN JAMISON, BEN PLOTKIN-SWING, BEN SCHWYN, SUBHADEEP GUPTA, University of Washington — Quantum mixtures of alkali and spin-singlet atoms offer new opportunities for studying few- and many-body physics, and also represent a starting point for producing paramagnetic polar molecules, of interest in various applications including quantum simulation and precision measurement. We report on studies of manipulating quantum mixtures of lithium (alkali) and ytterbium (spin-singlet) atoms by external magnetic fields. In one study, we achieve differential spatial control of the two atomic species by applying a magnetic gradient. Using this technique we are able to place bosonic $^{174}\text{Yb}$ inside a deeply Fermi degenerate $^6\text{Li}$ cloud as an interspecies probe. This gradient technique will also alleviate the relative gravitational sag for Li-Yb molecule formation work. In a separate study, we investigate the effect of $^{174}\text{Yb}$ on Li$_2$ dimer formation and stability near the broad $^4\text{Li}$ Feshbach resonance. The collisional stability of the Li-Yb mixture is adequate to allow time-resolved studies of these effects. We find evidence of modified Li$_2$ formation rate as well Li$_2$-Yb interactions. We will also report on studies of the Fermi-Fermi $^{174}\text{Yb}+^6\text{Li}$ system and outline prospects for future work.

1Supported by the National Science Foundation and Sloan Foundation.

K1.00122 Photoassociation of NaCs using chirped laser pulses. STEPHANE VALLADIER, University of Oklahoma — I present rates of photoassociation of NaCs from the continuum of the $X^1\Sigma^+$ electronic state to a set of high-lying rovibrational states of the $A^1\Sigma^+$ electronic state using chirped laser pulses. Chirping the pulse encompasses several energies of the scattering atoms from the continuum of the $X^1\Sigma^+$ state, thus addressing the issue of the thermal distribution. This work is a stepping stone towards rovibrational cooling of NaCs using chirped laser pulses and stimulated Raman adiabatic passage.
K1.00123 Dipole-dipole molecular scattering in electric and magnetic fields1. GOULVEN QUÉMÉNER, JOHN BOHN, JILA, University of Colorado, Boulder — The scattering of two molecules is determined in free space by their inter-molecular potential. In cold and ultracold gases this interaction can be dominated by long-range dipole forces, which can be manipulated by electric and magnetic fields. We investigate the scattering of two molecules possessing both electric and magnetic dipole moments, taking OH molecules as an example, in the presence of an electric and a magnetic field with an arbitrary relative angle. We will compare the effect of these long-range interactions on the differential cross sections with the field-free case. We will discuss the possibility of changing differential cross sections by adjusting different combinations of fields. We will focus on collisions in the ultracold regime as well as in the cold regime ($T \sim 100$ mK). We will also discuss the fate of these collisions if they occur in an optical lattice. 1We acknowledge funds from the Air Force Office of Scientific Research.

K1.00124 Light-assisted ion-neutral reactive processes in the cold regime: radiative molecule formation vs. charge exchange. OLIVIER DULIEU, Laboratoire Aime Cotton, CNRS, Universite Paris-Sud, Orsay, France, FELIX J. HALL, Department of Chemistry, University of Basel, Klingelbergstrasse 80, 4056 Basel, Switzerland, MIREILLE AYMAR, NADIA BOLOUFA, MAURICE RAOULT, Laboratoire Aime Cotton, CNRS, Universite Paris-Sud, Orsay, France, STEFAN WILLITSCHE, Department of Chemistry, University of Basel, Klingelbergstrasse 80, 4056 Basel, Switzerland — We present a combined experimental and theoretical study of cold reactive collisions between lasercooled Ca$^+$ ions and Rb atoms in an ion-atom hybrid trap. We observe rich chemical dynamics which are interpreted in terms of non-adiabatic and radiative charge exchange as well as radiative molecule formation using high-level electronic structure calculations. We study the role of light-assisted processes and show that the efficiency of the dominant chemical pathways is considerably enhanced in excited reaction channels. Our results illustrate the importance of radiative and non-radiative processes for the cold chemistry occurring in ion-atom hybrid traps.

K1.00125 Construction and characterization of tapered nano-fibers for hybrid quantum systems. J.E. HOFFMAN, J.A. GROVER, Z. KIM, J. LEE, K.D. VOIGT, I.D. SCHOCH, A.K. WOOD, J.R. ANDERSON, M. HAFEZI, C.J. LOBB, L.A. OROZCO, S.L. ROLSTON, J.M. TAYLOR, F.C. WELLSTOOD, Joint Institute for Quantum Studies, Department of Physics, University of Sao Paulo — We report the loading of a K crossed dipole trap directly from a regular K MOT. We start from a 300 $\mu$m MOT. In the sequence, we apply a molasses phase by varying the frequency and power of trapping and repumping beams, which allow us to cool the sample to 50 $\mu$K. Then the sample is loaded into a crossed broadband optical dipole trap. Our crossed beam configuration uses 25 W (at 1064 nm, bandwidth of 2 nm) in each beam with about 50 micron waist radius of the focus and a depth of about 700 $\mu$K. In the final sample, we have about 2 x 10$^6$ atoms, a temperature of 10 $\mu$K and a trap lifetime of 200 ms. The sample will be used for cold molecule experiments. 2We acknowledge financial support from FAPESP, CNPq, INCT-IQ.

K1.00126 Loading a K dipole trap from a MOT1. BRUNO MARANGONI, CARLOS MENEGATTI, LUIS MARCASSA, University of Sao Paulo — We report the loading of a K crossed dipole trap directly from a regular K MOT. We start from a 300 $\mu$m MOT. In the sequence, we apply a molasses phase by varying the frequency and power of trapping and repumping beams, which allow us to cool the sample to 50 $\mu$K. Then the sample is loaded into a crossed broadband optical dipole trap. Our crossed beam configuration uses 25 W (at 1064 nm, bandwidth of 2 nm) in each beam with about 50 micron waist radius of the focus and a depth of about 700 $\mu$K. In the final sample, we have about 2 x 10$^6$ atoms, a temperature of 10 $\mu$K and a trap lifetime of 200 ms. The sample will be used for cold molecule experiments. 2We acknowledge financial support from FAPESP, CNPq, INCT-IQ.

K1.00127 Advances in Bichromatic Force on Atoms and Molecules1. M.A. CHIEDA, E.E. EYLER, University of Connecticut — The optical bichromatic force (BCF) holds promise as an efficient, simple, and compact means to slow atoms and molecules to MOT capture velocities1. Metastable helium beams, with $v \sim 1000$ m/s, are especially worthwhile atomic candidates since they presently require Zeeman slowers with lengths of 2-3 m. We present a novel BCF decelerator in which the Doppler shifts are chirped to keep the force centered on the atoms as they slow. This is made possible by recent advances in high-power diode lasers and electronics, and avoids many of the problems of alternative designs using large detunings. Initial tests on He$^*$ atoms show encouraging results. Unlike atoms, direct laser slowing of molecules remains exceedingly difficult, although success with SrF has very recently been reported1. We calculate that for molecules with near-cycling transitions, rapid laser BCF slowing should be possible.1 For the CaF molecule, we predict slowing by $\Delta v = 150$ m/s, enough to bring a buffer-gas cooled beam to rest. An experimental demonstration is in progress. 1Sponsored by the University of CT Research Foundation and NSF. 2M. Cashen and H. Metcalf, JOSA B 20, 915 (2003). 3M. A. Chieda and E. E. Eyler, PRA 84, 063401 (2011). 4J. F. Barry, E. S. Shuman, E. B. Norrgard, and D. DeMille, to be published. 5Chieda, op. sit.

K1.00128 A Rb D1 MOT for Simulating a SrF MOT1. ERIC NORRGARD, TOSHIHIKO SHIMASAKI, JOHN BARRY, COLIN BRUZEWICZ, MATT STEINECKER, DAVID DEMILLE, Yale University — Our group recently demonstrated transverse laser cooling and longitudinal laser slowing of a buffer-gas-cooled beam of polar molecules (SrF). Work is underway to load these slow molecules into a magneto-optical trap (MOT). A SrF molecular MOT presents a number of complications not present in a usual alkali MOT. The standard MOT design uses a cycling transition on the D2 line of an alkali. The level structure of SrF precludes the use of a true two-level cycling transition; instead, due to the existence of dark Zeeman sublevels, it is at first glance unclear whether a net trapping force can be applied. However, a closely analogous situation occurs in an alkali D1-line MOT, which has been experimentally demonstrated to be effective despite this level structure. This poster details ongoing investigations of a Rb D1 MOT, intended to better understand effects associated with this nonstandard level structure on the behavior of a MOT design, in particular when applied to SrF. 1This work is supported by NSF GRFP, DOE, and AFOSR-MURI.
K.001129 Velocity Dependence of the Optical Force Produced by Adiabatic Rapid Passage\textsuperscript{1}, DANIEL STACK, JOHN ELGIN, PETR M. ANISIMOV, HAROLD METCALF, Stony Brook University, Stony Brook, NY 11794-3800 — Adiabatic Rapid Passage (ARP) produces optical forces much larger than the ordinary radiative force, and is thought to work best when $\Omega_{0} > \delta_{0} \gg \omega_{m} \gg \gamma$, where $\Omega_{0}$, $\delta_{0}$, $\omega_{m}$, and $\gamma$ are the Rabi frequency, sweep range, sweep rate, and natural decay rate respectively. We have observed strongly enhanced ARP forces on the $^{2}\text{S}_{1} - ^{2}\text{P}_{2}$ transition of He outside of this parameter range with our improved apparatus described previously\textsuperscript{2}. Our independent counter-propagating, chirped pulses allow greater freedom in the choice of relative beam parameters so we can detune the beams to simulate atomic motion. We will present our new data on the velocity dependence of the ARP force and compare these with our calculations\textsuperscript{3}.

\textsuperscript{1}Supported by ONR.
\textsuperscript{2}D. Stack et al., Bull. Am. Phys. Soc. 56, 153 (2011)
\textsuperscript{3}D. Stack et al., Phys. Rev. A, 84, 013420 (2011)

K.001130 Toward a 2-D magneto-optical trap for polar molecules\textsuperscript{1}, MATTHEW HUMMON\textsuperscript{2}, BENJAMIN STUHL, MARK YEO, ALEJANDRA COLLOPY, JUN YE, JILÁ, University of Colorado, Boulder — The additional structure that arises from the rotational degree of freedom in diatomic molecules makes difficult the interaction of electromagnetic fields with a magneto-optical trap (MOT) for use with molecules. We describe progress toward development of a 2-D MOT for laser cooled yttrium monoxide molecules based on a resonant LC baseball coil geometry.

\textsuperscript{1}We acknowledge support from the AFOSR and the NSF.
\textsuperscript{2}M. H. acknowledges support from an NRC Postdoctoral Fellowship

K.001131 Transport coefficients for electrons in Hg vapor. SASA DUJKO, Institute of Physics, University of Belgrade, PO Box 68, Zemun 11080, Belgrade, Serbia, RON WHITE, ARC Centre for Antimatter-Matter Studies, School of Engineering and Physical Sciences, James Cook University, Townsville 4810, Australia, ZORAN PETROVIC, Institute of Physics, University of Belgrade, PO Box 68, Zemun 11080, Belgrade, Serbia — Transport coefficients and distribution functions are calculated for electrons in Hg vapor under warm conditions using a multi term theory for solving the Boltzmann equation, over a range of $E/N$ values and temperatures relevant to lamp discharges. It is shown that for higher $E/N$ the electron distribution is non-thermal for all Hg vapor temperatures considered, and that the speed distribution function significantly deviates from a Maxwellian under these conditions. Our work has been motivated, in part, by recent suggestions that highly accurate data for transport coefficients required as input in fluid models of Hg vapor lamp discharges may significantly improve the existing models. Current models of such lamps require a knowledge of the plasma electrical conductivity, which can be calculated from the cross sections for electron scattering in Hg vapor and mobility coefficients presented in this work. The effect of metastable atoms on the swarm parameters is also discussed. The influence of a magnetic field on electron transport coefficients in Hg vapor is investigated over a range of $E/N$ values and angles between the fields.

K.001132 High order fluid model of streamer discharge in molecular nitrogen, SASA DUJKO, Institute of Physics, University of Belgrade, PO Box 68, Zemun 11080, Belgrade, Serbia, ARAM MARKOSYAN, Centrum Wiskunde & Informatica (CWI), P.O.Box 94079, 1090 GB Amsterdam, The Netherlands, RON WHITE, ARC Centre for Antimatter-Matter Studies, School of Engineering and Physical Sciences, James Cook University, Townsville 4810, Australia, ZORAN PETROVIC, Institute of Physics, University of Belgrade, PO Box 68, Zemun 11080, Belgrade, Serbia, UTE EBERT, Centrum Wiskunde & Informatica (CWI), P.O.Box 94079, 1090 GB Amsterdam, The Netherlands — In this work, we present the basic elements of a theory developed for high order fluid modeling of streamer discharges. Using a momentum transfer theory, the first four moments of the Boltzmann equation are closed in the local mean energy approximation and coupled to the Poisson equation for space charge electric field. The high order pressure tensor appearing in the heat flux equation is specified in terms of previous moments. The average collision frequencies for momentum and energy relaxation and the average energy loses in inelastic collisions are calculated using the cross sections for electron scattering as input into a multi term Boltzmann equation solution. Negative streamer ionization fronts in nitrogen under normal conditions are investigated and it is shown that the high order fluid model involving the solution of the energy flux equation with the local mean energy approximation must be used in order to accurately simulate the streamer dynamics.

K.001134 Nuclear Spin-Dependent Parity Violation in Diatomic Molecules, JEFFREY AMMON, SIDNEY CAHN, EMIL KIRILOV, DAVID DEMILLE, Yale University, MIKHAIL KOZLOV, Petersburg Nuclear Physics Institute, RICHARD PAOLINO, U.S. Coast Guard Academy — Nuclear spin-dependent parity violation (NSD-PV) effects arise from exchange of the $Z$ boson (parametrized by the electroweak coupling constants $C_{P,N}$) between electrons and the nucleus, and from the interaction of electromagnetic fields with the nuclear anapole moment, a parity-odd magnetic moment. The latter scales with the nucleon number $A$ of the nucleus as $A^{1/2}$ while the $Z^{0}$ coupling is independent of $A$; the former will be the dominant source of NSD-PV in nuclei with $A$ greater than 20. NSD-PV effects can be dramatically amplified in diatomic molecules by bringing two levels of opposite parity close to degeneracy in a strong magnetic field. This opens the prospect for measurements across a broad range of nuclei. As a precursor to the measurement of the nuclear anapole moment of $^{137}$Ba, we have experimentally observed and characterized opposite-parity level crossings in $^{138}$Ba. These are found to be in excellent agreement with parameter-free predictions and indicate that the sensitivity necessary for NSD-PV measurements should be within reach.

K.001135 Testing gravity at the micro-scale with laser-cooled trapped microspheres, DAVID ATHERTON, MELANIE BECK, CHRIS THOMÁS, ANDREW GERRI, University of Nevada, Reno — In ultra-high vacuum, optically-trapped and cooled dielectric microspheres show great promise as force sensors. The environmental decoupling of their center-of-mass motion enables sub-Rayleigh velocity sensitivity. Hence, they can be used to investigate Casimir forces or for testing non-Newtonian gravity \cite{1}. We are developing an apparatus to trap and cool silica spheres in a combined optical dipole-cavity trap. The cavity will be filled with two laser fields to trap and cool the sphere center of mass motion, respectively. We have observed strongly enhanced ARP forces on the $^{2}\text{S}_{1} - ^{2}\text{P}_{2}$ transition of He outside of this parameter range with our improved apparatus described previously\textsuperscript{2}. Our independent counter-propagating, chirped pulses allow greater freedom in the choice of relative beam parameters so we can detune the beams to simulate atomic motion. We will present our new data on the velocity dependence of the ARP force and compare these with our calculations\textsuperscript{3}.

\textsuperscript{1}A.A.Geraci, S.B.Papp, and J.Kitching, Phys. Rev. Lett. 105, 101101 (2010).

K.001136 Progress toward a measurement of the electron's electric dipole moment using PbO, STEPHEN ECKEL, PAUL HAMILTON, EMIL KIRILOV, HUNTER SMITH, DAVID DEMILLE, Yale University — Searches for permanent electric dipole moments (EDMs) of fundamental particles provide a way to detect new sources of time-reversal symmetry violation. We present recent results on an experiment to search for the electron's EDM, using the polar molecule PbO. PbO offers several advantages compared to atoms, including a much larger effective internal electric field ($> 10$ GV/cm) and parity doubling, which can be used to reverse the effective internal electric field without reversing the laboratory electric field. This technique allows for significant reduction of systematic errors. Recent improvements to the experiment have resulted in statistical sensitivities of approximately $1 \times 10^{-27}$ ecm/$\sqrt{\text{day}}$, which could allow for an improvement over the current experimental limit on the electron EDM in only a few days of integration time. Details of the approach and studies of possible systematic errors will be described.
K1.00137 Proposed search for T-odd, P-even interactions in spectra of chaotic atoms with frequency combs1. MUIR MORRISON, ANDREI DEREVIANKO, University of Nevada, Reno, M.G. KOZLOV, Petersburg Nuclear Physics Institute — Violation of fundamental symmetries in atoms has been the subject of intense experimental and theoretical interest. P-odd, T-even transitions have been observed and are in excellent agreement with electroweak theory. Electron EDM searches have placed bounds on T-odd, P-odd interactions, constraining proposed extensions to the Standard Model. In this work we propose a search for T-odd, P-even (TOPE) interactions in atoms, which have thus far received little attention. We consider open-shell atoms (such as the rare earths) which have dense, chaotic excitation spectra with strong level repulsion. The strength of the level repulsion depends on the underlying symmetries of the atomic Hamiltonian. TOPE interactions lead to increased level repulsion. We will demonstrate how a statistical analysis of many chaotic spectra can determine the strength of level repulsion; in particular, the variance of the number of levels in an energy range has been shown to be a useful measure. We estimate that, using frequency comb spectroscopy, a sufficient number of chaotic levels could be measured to match or exceed the current experimental bounds on TOPE interactions.

1This work was supported in part by the NSF.

K1.00138 Progress towards an electron EDM measurement using trapped hafnium fluoride ions1, MATT GRAU, HUANQIAN LOH, ERIC A. CORNELL, JILA, NIST and University of Colorado (Boulder), and Department of Physics, University of Colorado (Boulder) — Trapped molecular ions are an ideal platform for precision measurement of the electron electric dipole moment (eEDM). The low lying electronic state of HfF+ is predicted to contribute a large sensitivity enhancement to an eEDM measurement. We create HfF+ by optically exciting a supersonic beam of HIF with two photons to an autoionizing state. We then load the HfF+ into a novel Paul trap optimized for fluorescence collection and field uniformity. We report on recent experiments in the trap, and on our general progress towards the eEDM measurement. This work is funded by the National Science Foundation and the Marsico Endowed Chair.

1Work supported by the NSF.

K1.00139 The ACME electron electric dipole moment experiment1. BRENDON O’LEAN, CHEONG CHAN, DAVID DEMILLE, Yale University, JOHN DOYLE, GERRY GABRIELSE, PAUL HESS, NICK HUTZLER, Harvard University, EMIL KIRILOV, Yale University, ELIZABETH PETRIK, BEN SPAUN, Harvard University, ACME COLLABORATION — The ACME collaboration is searching for the electron’s electric dipole moment (eEDM) using a buffer gas-cooled beam of ThO molecules in their metastable H$^3\Delta_1$ state. We discuss details of the design, assembly, and current status of this experiment. We also describe progress towards potential future improvements in the signal-to-noise in future generations of ACME.

1Supported by the NSF.

K1.00140 ABSTRACT WITHDRAWN

K1.00141 Progress Toward a Two-Photon Optical Atomic Clock in Neutral Silver1, DAVID MCKENNA, CAROL TANNER, University of Notre Dame — Bender et al\cite{1} proposed Ag as an optical frequency standard. There are two narrow two-photon transitions 4d10s5 2S1/2-4d9s2 2D5/2 (two 661nm photons) and 4d10s5 2S1/2-4d9s2 2D3/2 (two 576nm photons) from the ground state. An advantage over single-photon optical clocks is that two equal counter-propagating photons will cancel the first order Doppler shift. The 4d9s2 2D3/2 state (width 4kHz) decays by two single photon emissions to the ground state via easily detectable photons at 338nm or 328nm. The 4d9s2 2D5/2 state is metastable (width 45Hz) and decays via an electric quadrupole transition at 330nm. Our first goal is to observe excitation and decay of the 4d9s2 2D3/2 (width 4kHz) state.

1Supported by a NIST Precision Measurements Grant.


K1.00142 Development of Al+ optical clocks1. JW-O-SY CHEN, KANG-KUEN NI, CHIN-WEN CHOU, DAVID J. WINELAND, TILL ROSENBAND, National Institute of Standards and Technology — Low sensitivity to electromagnetic fields and a narrow natural line width have enabled the S$^0_0$- S$^0_2$ transition in Al+ to achieve 8.6 x 10^-18 accuracy. This allows for precise gravitational red-shift measurements with possible applications in geodesy, hydrology, and other fundamental tests of physics. However, the current laboratory system is not yet usable for these applications, due to the complexity of operation. We report recent progress towards the goals of higher accuracy and simplified non-laboratory operation of Al+ clocks.

1Supported by DARPA, AFOSR, and ONR.

K1.00143 Test of Lorentz Invariance at the South Pole Using a Rotating Co-magnetometer1, MARC SMICKLASS, MICHAEL ROMALIS, Princeton University — Among various experiments used to test Lorentz invariance, one of the most sensitive laboratory techniques is a measurement of nuclear spin-precession, descendant from the original Hughes and Drever experiments. In recent years, our rotating co-magnetometer has set the most stringent limits on vector and tensor Lorentz violation for fermions. A major limiting factor of spin-precession measurements is a large background signal due to the projection of the Earth’s rotation onto the sensitive axis of the co-magnetometer, which also acts as a sensitive gyroscope. To greatly suppress this background, we present our plans to move the rotating co-magnetometer experiment to the South Pole Station, where the Earth’s rotation direction and the direction of local gravity coincide. Rotating the co-magnetometer around this axis will eliminate any terrestrial background signals. We will present the latest results for the short-term sensitivity of the comagnetometer, which should enable an improvement of the current Lorentz-violation limits by three orders of magnitude at the South Pole.

1This research funded by NSF grant #Phy-0969862.

K1.00144 SPECIAL TOPICS (EXOTIC ATOMS AND MOLECULES; NONLINEAR DYNAMICS; NEW EXPERIMENTAL AND THEORETICAL METHODS; APPLICATIONS OF AMO SCIENCE) II —
K1.00145 Magnetic Coil Design and Analysis  . MICHAEL BULATOWICZ, Northrop Grumman — Modified magnetic field coil geometries as described in U.S. Patent Applications US20100194506 and US20110247414 can produce substantially greater magnetic field homogeneity as compared to the traditional realized versions of idealized magnetic coil geometries such as spherical or Helmholtz. The new coil geometries will be described in detail and will be compared and contrasted to realized versions of idealized geometries, including discussion of errors not typically accounted for in traditional coil design and analysis.

K1.00146 Positrons for Antihydrogen with ATRAP: efficient transfer of large positron numbers 2 . CODY STORRY, DANIEL COMEAU, ASAF DROR, DANIEL FITZAKERLEY, MATTHEW GEORGE, ERIC HESSELS, MATTHEW WEELE, York University, ATRAP COLLABORATION 2 — Positrons accumulated in a room-temperature buffer-gas-cooled positron accumulator are efficiently transferred into a superconducting solenoid which houses the ATRAP cryogenic Penning trap for antihydrogen research. The positrons are guided along a 9-meter-long magnetic guide which connects the central field lines of the 0.15-tesla field in the positron accumulator to central magnetic field lines of the superconducting solenoid. Seventy independently-controllable electromagnets are required to overcome the fringing field of the large-bore superconducting solenoid. The guide includes both a 15 degree upward bend and a 105 degree downward bend to account for the orthogonal orientation of the accumulator with respect to the cryogenic Penning trap. Low-energy positrons ejected from the accumulator follow the magnetic field lines within the guide and are transferred into the superconducting solenoid with nearly 100% efficiency. 7 meters of 5-cm-diameter stainless-steel tube, and a 20-mm-long, 1.5-mm-diameter cryogenic pumping restriction ensure that the 10^{-2} mbar pressure in the accumulator is well isolated from the extreme vacuum required in the Penning trap to allow long antimatter storage times.

1NSERC, CRC, OIT, CFI

K1.00147 Miniature, atomically referenced offset phase-locked laser for cold-atom sensors 1 . JUAN PINO, BEN LUEY, SARAH BICKMAN, MIKE ANDERSON, Vescent Photonics — As ultracold atom sensors begin to see their way to the field, there is a growing need for small, accurate, and robust laser systems to cool and manipulate atoms for sensing applications such as magnetometers, gravimeters, atomic clocks and inertial sensing. In this poster we present an ultracompact, frequency agile laser source, referenced to a hyperfine transition of ^{87}Rb. The laser system is housed in a package roughly the size of a stack of business cards, is hermetically sealed, and contains no moving parts – ideal for field deployment. The laser system includes two lasers with independent temperature control, a Rb-filled vapor cell, a high-speed photodetector for monitoring the offset frequency between the lasers, as well the necessary optical isolation. We will present designs of the ultracompact laser system, as well as quantitative results including size, weight, expected power consumption, frequency agility, and frequency stability.

1This work was funded by DARPA.

K1.00148 Design and construction of tapered amplifier systems for the advanced undergraduate laboratory 1 . JAYAMPATHI KANGARA, ANDREW HACHTEL, JASON BARKELOO, JEFFREY KLEYKAMP, MATTHEW GILLETTE, SAMIR BALI, Department of Physics, Miami University — We report on the design and construction of tapered amplifier (TA) systems in a primarily undergraduate setting, each system costing less than $4000 to build. Plots of power output are presented versus seed power and TA current, including plots of TA output coupled through a single-mode optical fiber. We acknowledge invaluable discussions with Prof. D. Steck’s group at Univ. of Wisconsin, Madison on the optics for collimation of the seed laser into the TA chip, and of the TA output. Also, we have based our current and temperature drivers for the TA system on circuit designs by Prof. D. Steck’s group at the Univ. of Oregon, Eugene.

1We gratefully acknowledge financial support from Petroleum Research Fund.

K1.00149 Unitary Penning traps  . JOSEPH TAN, National Institute of Standards and Technology, SAMUEL BREWER, University of Maryland at College Park, NICHOLAS GUISE, NIST — We have constructed Penning traps in extremely compact forms, with unitary architectures that fully integrate NdFeB magnets (1.2 Tesla remnant magnetic field) within the electrode structure (occupying < 150 cm^3 assembled). A room-temperature apparatus has proven to be very useful in slowing and capturing ions extracted from an electron beam ion trap (EBIT). Here we present a two-magnet Penning trap designed to facilitate ion manipulation and optical experiments with stored ions. Some test results are presented. Experiments using this novel apparatus have proven to be very useful in slowing and capturing ions extracted from an electron beam ion trap (EBIT) and in facilities or missions that have severe space constraints.

2N.D. Guise, et al., “Charge exchange and spectroscopy with isolated highly-charged ions,” at this meeting.
3S. M. Brewer, et al., “Observing forbidden radiative decay of highly-charged ions in a compact Penning trap,” at this meeting.

K1.00150 Technique for Elimination of Excited States from Atomic and Molecular Ion Beams  , C.R. VANE, M.E. BANNISTER, C.C. HAVENER, YUAN LIU, Oak Ridge National Laboratory, Oak Ridge, TN 37831-6372 — Fundamental interactions of atomic and molecular ions with electrons, neutral atoms and molecules, surfaces, and photons play major roles in many important plasma and chemical environments. Achieving a detailed understanding of these interactions is often complicated by the presence of uncharacterized populations of electronic or vibrational excited states, especially in making direct comparisons with theoretical predictions problematic. We are developing experimental techniques for reducing or eliminating ion source-generated excited states in atomic and molecular ion beams using a gas-filled RF quadrupole (RFQ) ion cooler, through natural radiative cooling during ion transit, and by preferential quenching in charge transfer collisions with selected buffer gases. Technical details and progress toward these goals will be presented. Research sponsored by the Laboratory Directed Research and Development Program of Oak Ridge National Laboratory, managed by UT-Battelle, LLC, for the U. S. Department of Energy.
K.00151 3 Watt CW OPO tunable 604nm to 616nm for quantum optics applications

ANGUS HENDERSON, Lockheed Martin Aculight, THOMAS HALFMANN, SIMON MIETH, Institute of Applied Physics, Technical University of Darmstadt — A continuous wave optical parametric oscillator (CW OPO) pumped by a fiber laser has been developed which emits up to 3 Watts of single longitudinal mode radiation tunable in the wavelength range 604nm to 616nm. The device is a modified version of the "Argos" Model 2400 commercial product by Lockheed Martin Aculight. A 15 Watt 1064nm fiber laser pumps a CW OPO based upon periodically-poled Lithium Niobate (PPLN). A short section of the nonlinear crystal is poled to allow efficient intracavity sum frequency generation (SGF) between the OPO pump and signal wavelengths to generate orange radiation. The device can be conveniently tuned by adjusting the poling period. The temperature within the nonlinear crystal to phase-match both SGF processes simultaneously. Fine mode-hop-free tuning of the orange wavelength of up to 100GHz range can be achieved by applying a voltage to a PZT which tunes the pump laser. By similar intracavity conversion systems, the device offers the potential of providing high power at wavelengths from 600nm to 1400nm in addition to the direct signal and idler wavelength ranges from 1400nm to 4630nm. Such capability comes without the complexity and reliability issues which are inherent in dye and Ti:Sapphire systems. Details of the OPO system performance and its use in quantum optics applications will be provided.

K.00152 ATTA Device for Measuring Trace Kr Contamination in Xenon Dark Matter Detectors, LUKE GOETZKE, TAE HYUN YOON, ANDRE LOOSE, ELENA APRILE, TANYA ZELEVINSKY, Columbia University — The XENON dark matter experiments search for low-energy elastic scattering events of Weakly Interacting Massive Particles (WIMPs) off Xe nuclei. For Xe targets and other noble liquids used in rare process searches, Kr contamination contributes background events through the beta decay of long-lived radioactive Kr-85. To achieve the sensitivity required of the next generation of dark matter detectors, the Kr contamination must be reduced to less than one part per trillion (ppt). We have developed an Atom Trap Trace Analysis (ATTA) device to measure Kr/Xe at the ppt level. Metastable Kr-84 is cooled and trapped in a magneto-optical trap, and imaged with a sensitive photodetector. Since Ar and Kr have similar wavelengths, the apparatus has been initially tested with Ar to avoid contamination. Results from tests with Ar and single atom detection with Kr will be presented.

K.00153 Progress Towards Room-Temperature Electron Spin Detection in Biological Systems, NICHOLAS CHISHOLM, IGOR LOVCINSKY, ALEX SUSHKOV, Harvard University, DAVID HUNGER, Max-Planck-Institut für Quantenoptik Garching, Ludwig-Maximilians-Universität München, ALEXEY AKIMOV, PEGGY LO, AMY SUTTON, JACOB ROBINSON, NORMAN YAO, STEVEN BENNETT, HONGKUN PARK, MIKHAIL LUKIN, Harvard University — We report on recent progress of room-temperature electron spin sensing for biological applications using nitrogen-vacancy (NV) centers in diamond. Room-temperature detection of a small number of electron spins, situated outside the measurement substrate, has yet to be accomplished. Such an advance could lead to a number of applications, including detection of magnetic resonance signals from individual electron or nuclear spins of complex biological molecules, measurement of concentrations of radicals in living cells, and monitoring the ion channel function across cell membranes (important for exploring drug delivery mechanisms). Thus, the ability to measure magnetic fields with sensitivity allowing detection of a small number of electron spins with sub-micrometer resolution would be of major importance to the biological sciences.

K.00154 Generation of a green astro-comb using tapered photonic crystal fibers, DAVID PHILLIPS, ALEXANDER GLENDAY, CHIH-HAO LI, GABOR FURESZ, NICHOLAS LANGELLEUR, Harvard-Smithsonian, MATTHEW WEBBER, Northeastern University, GUOQING CHANG, LI-JIN CHEN, HUNG-WEN CHEN, JINKANG LIM, FRANZ KAERTNER, Massachusetts Institute of Technology, ANDREW SZEPTY-ORGYI, RONALD WALSWORTH, Harvard-Smithsonian — Searches for exoplanets using precision stellar radial velocity (PRV) measurements are approaching Earth-like planet sensitivity. Astro-combs, which consist of a laser frequency comb, coherent wavelength shifting mechanism (such as a doubling crystal or photonic crystal fiber), and a mode-filtering Fabry-Perot cavity, provide a promising route to increased accuracy and long-term stability of the astrophysical spectrometer. We have developed a 1064nm fiber laser pumped 3 Watt CW OPO tunable 604nm to 616nm for quantum optics applications. Now, we report an astro-comb built using a similar 1064nm OPO and a mode-filtering Fabry-Perot cavity for improved sensitivity of the astrophysical spectrometer. A green astro-comb promises to improve the signal-to-noise ratio of astronomical observations by a factor of 10 compared to the best-optimized current astro-comb. Thus, we have used the 1064nm laser output in a non-collinear optical parametric oscillator to produce light across the visible spectrum, with the potential of extending to wavelength beyond 1600nm via a cascaded optical parametric generator. In addition, a Fabry-Perot cavity, provided by a pair of complementary chirped mirrors.

K.00155 Bioimaging Applications Using Color Centers in Diamond, DAVID GLENN, HUILIANG ZHANG, ANAT BENADO, Harvard-Smithsonian Center for Astrophysics, NARAYANAN KASTHURI, RICHARD SCHALEK, Harvard Center for Brain Science, JEFF LICHTMAN, Harvard Department of Molecular and Cell Biology, RONALD WALSWORTH, Harvard-Smithsonian Center for Astrophysics — Color centers in diamond offer significant opportunities for the development of new techniques in bioimaging. We present recent work on the application of various color centers in nanodiamond as cathodoluminescent probes for efficient microscopy. We also discuss progress on the use of bulk diamond samples with surface-implanted nitrogen-vacancy (NV) layers for magnetic field sensing, with the specific goal of making sensitive, spatially-localized measurements of free radical concentrations in biological systems.

K.00156 Adventures in Alignment-Based Magnetometry, B. PATTON, Department of Physics, UC Berkeley, O.O. VERSOLATO, Kernfysisch Versneller Instituut, University of Groningen, The Netherlands, E. CORSINI, Department of Physics, UC Berkeley, D.C. HOVDE, Southwest Sciences, Inc., S. ROCHESTER, Department of Physics, UC Berkeley, D. BUDKER, Department of Physics, UC Berkeley and Nuclear Science Division, Lawrence Berkeley National Laboratory — Alkali-vapor magnetometers constitute the world’s most precise magnetic sensors to date. Typically such devices employ circularly polarized light and thus rely upon orientation, the lowest-order polarization moment which can be excited in an alkali atom. To find the sensitivity required of the next generation of alignment-based magnetometers, with particular focus on the systems of systematic errors such as heading error, such errors will be addressed in the context of a self-oscillating magnetometer, along with the prospect of completely remote magnetometry performed over a large free-space distance.

Wednesday, June 6, 2012 4:00PM - 5:30PM – Session K3 Tutorial for Authors and Referees Grand Ballroom E

4:00PM K3.00001 Tutorial for Authors and Referees — How do you get a paper accepted in PRA or PRL? What happens once you have submitted a manuscript, or a referee report? What’s new about the journals? Learn how to write a good referee report, and how (not) to rebut one. What do editors like to see in a title, abstract, introduction, or conclusion? Come hear the editors talk, ask them questions, and tell them what you think! The session will begin with a short talk aimed at (not only) newer authors and referees, followed by a brief discussion of recent developments surrounding the journals. After that, the floor will be opened up for a panel discussion and questions about all matters Physical Review. Audience participation is strongly encouraged!

Wednesday, June 6, 2012 5:00PM - 6:00PM – Session K5 Topical Group on Precision Measurements and Fundamental Constants Meeting Garden 3
Atomic pairs. For the lowest vibrational levels the dispersion coefficient $C_6$ demonstrates that the binding energy of rotational biexcitons can be controlled by tuning the angle between the applied field and the molecular array. Frenkel biexcitons are strongly correlated states of two collective excitations in a molecular crystal, which are exceedingly hard to create and observe in solid-state crystals. We show that non-linear interactions between these excitons can be tuned by applying a dc electric field. We show that, at electric fields greater than a critical value, rotational Frenkel excitons form bound pairs—biexcitons—within multichannel quantum defect theory. Uniting these two techniques, we can assess the influence of “über-resonant” scattering in a statistical manner while treating the physics of the long-range scattering, which is sensitive to such things as hyperfine states, collision energy and any applied electromagnetic fields, exactly within multichannel quantum defect theory. Uniting these two techniques, we can assess the influence of “über-resonant” scattering in the threshold regime, and in particular its dependence on the hyperfine state selected for the collision. This allows us to explore effects such as the onset of so-called Ericson fluctuations, which are well-known in nuclear physics but completely new in the ultracold domain.

We acknowledge financial support from the U.S. DOE. M.M. acknowledges financial support by a fellowship within the postdoc-programme of the German Academic Exchange Service (DAAD).

1 We acknowledge financial support from the U.S. DOE. M.M. acknowledges financial support by a fellowship within the postdoc-programme of the German Academic Exchange Service (DAAD).

8:24AM M1.00003 Dynamics of strongly reactive molecules, MICHAEL FÖSS-FEIG, ANA MARIA REY, JILA, NIST, and University of Colorado at Boulder — As degenerate gases of ground-state polar molecules approach realization [1], it is increasingly important to understand the effects of lossy interactions on quantum simulations. We explore the dynamics of strongly reactive molecules in a variety of lattice geometries, and point out ways in which losses can be used as ideal probes of these systems. We further explore the use of losses as projective measurements onto entangled subspaces [2], and discuss realistic implementations of these ideas with ground-state molecules.


8:36AM M1.00004 Frenkel biexcitons in optical lattices with polar molecules, MARINA LITINSKAYA, PING XIAO, ROMAN KREMS, University of British Columbia — Rotational excitation of ultracold polar molecules trapped on an optical lattice produces rotational Frenkel excitons (collective rotational excitations) [1]. We show that non-linear interactions between these excitons can be tuned by applying a dc electric field. We show that, at electric fields greater than a critical value, rotational Frenkel excitons form bound pairs—biexcitons [2]. Frenkel biexcitons are strongly correlated states of two collective excitations in a molecular crystal, which are exceedingly hard to create and observe in solid-state crystals. We demonstrate that the binding energy of the rotational biexcitons can be controlled by tuning the angle between the applied field and the molecular array. Frenkel biexcitons can be used for many applications ranging from the controlled preparation of entanglement between quasi-particles to the study of bipolarons.

8:48AM M1.00005 Spectroscopy of $^{39}$K$^{85}$Rb electronic states in the predicted region of resonantly coupled excited states for the direct formation of the $X(0,0)$ state$^1$. JAYITA BANERJEE, DAVID RAHMLOW, RYAN CAROLLO, MICHAEL BELL, MATTHEW BERMUDEZ, EDWARD EYLER, PHILIP GOULD, WILLIAM STWALLEY, Department of Physics, University of Connecticut — The $2^{1}I(\nu=17)$ and $2^{1}I(\nu=60)$ vibrational levels of KRb are predicted to be resonantly coupled, based on extrapolation from high rotational levels reported in [1] to $J'=1$ [2], and on tentative assignments of photoassociation spectra in the region near 12535cm$^{-1}$ [3]. Access to the $2^{1}I$ levels is desirable for formation of ultracold KRb molecules in their ground $X^1\Sigma^+$, $\nu=0$, $J=0$ level because of strong Franck-Condon overlap [3]. The $1^{1}I$ component of these two mixed states provides PA access to short range region where $2^{1}I$ emission to the X($0,0$) level can occur. Experiments are being carried out to better understand the spectra and perturbations in the region near 12535cm$^{-1}$, which should include $3(0^+)$, $2(1)$, $4(1)$, $5(1)$ and possibly other states. The $4(1)$ and $5(1)$ long-range states correlate with $1^{1}I$ and $2^{1}I$ short-range states. These studies have also produced new information on efficient formation of specific vibrational levels in $a^3\Sigma^+$ state and new data on $3^3\Sigma^+$ and $3^3I$ states.

$^1$Supported by AFOSR(MURI) and NSF.

9:00AM M1.00006 Rotational Optical Pumping of NaCs, MAREK HARUZA, PATRICK ZABAWA, AMY WAKIM, NICHOLAS BIGELOW, University of Rochester, Rochester, NY — We demonstrate efficient cooling of the rotational degree of freedom of ultracold NaCs molecules through narrow line optical pumping. Molecules in $v'=0$, $N'=2$ and $4$ are excited to the lowest vibrational level of the $A^1\Sigma^+ \rightarrow b^1I$ complex from which they decay to $v''=0$, $N''=0$. We achieve cooling of both rotational and vibrational degrees of freedom by applying this technique in conjunction with broadband optical pumping [1]. This technique also allows transfer of population between any of the lowest vibrational states ($v'=0$) at kHz rates.

$^1$Supported by the Department of Energy, Office of Basic Energy Sciences

9:12AM M1.00007 Threshold resonances in ultracold chemical reactions$^1$. ROBIN CÔTÉ, IONEL SIMBOTIN, SUBHAS GHOSAL, Department of Physics, University of Connecticut, 2152 Hillside Rd., Storrs, CT 06066, USA — We analyze the effects of near threshold resonances on the low energy behavior of cross sections for reactive scattering systems with reaction a barrier (e.g. Cl + H$_2$, D + H$_2$). We find an anomalous behavior when a resonance pole is very close to the threshold of the entrance channel. For inelastic processes, including reactive ones, the anomalous energy dependence of the cross sections is given by $\sigma \sim E^{-3/2}$. However, at vanishingly low energies, the standard Wigner's threshold behavior ($\sigma \sim E^{-1/2}$) is eventually recovered, but limited to much narrower range of energies. When the cross sections are averaged to obtain rate coefficients, the anomalous behavior persists; indeed, we find an intermediate regime of ultralow temperatures, where the inelastic rate coefficients behave as $K \sim 1/T$.

$^1$Department of Energy, Office of Basic Energy Sciences; AFOSR MURI grant on ultracold polar molecules

9:24AM M1.00008 Photoassociation of alkali tetramers into high vibrational states$^1$. JASON BYRD, SUBHAS GHOSAL, JOHN MONTGOMERY, JR, ROBIN CÔTÉ, University of Connecticut — The formation of alkali tetramers in high vibrational states from two polar molecules, $XY+XY \rightarrow X_Y^2Y_Z$, using photoassociation has been investigated for various species. Diatom-diatom interaction surfaces have been calculated using $ab$ initio equation of motion coupled cluster and time dependent density functional van der Waals methods. Using an external electric field to improve the associated Franck Condon factors, we propose a two color time dependent wavepacket scheme to probe the high vibrational level states of various alkali tetramers.

$^1$Department of Energy, Office of Basic Energy Sciences; AFOSR MURI grant on ultracold polar molecules

9:36AM M1.00009 Molecule-molecule hyperfine Feshbach resonances, ALISDAIR WALLIS, ROMAN KREMS, University of British Columbia — Magnetic Feshbach scattering resonances play a central role in experimental research of atomic gases at ultracold temperatures. A major thrust of current research is to create an ultracold gas of diatomic alkali-metal molecules in the ground rovibrational state of the ground electronic $1^1\Sigma^+$ state. Can ultracold $1^1\Sigma^+$ molecules be controlled by means of magnetic Feshbach resonances? Unlike alkali metal atoms, $1^1\Sigma$ diatomic molecules have no unpaired electrons. The response of $1^1\Sigma$ molecules to an external magnetic field is determined entirely by the spin structure of the atomic nuclei. We present the first calculations of molecule-molecule collisions for $1^1\Sigma$ molecules in a magnetic field. In particular, we calculate the rates of hyperfine relaxation in molecule-molecule collisions and explore the possibility of tuning magnetic Feshbach resonances in an ultracold gas of $^{87}\text{Rb}^{133}\text{Cs}(X^1\Sigma^+)$ molecules.

9:48AM M1.00010 Cold dipolar collisions in magnetically trapped OH$^1$. BENJAMIN STUHL, MARK YEO, MATT HUMMON$^2$, JUN YE, JILA / University of Colorado and NIST — A major open question in cold molecular physics is the universality of dipole-dipole scattering in real molecules. So far, the relationship between dipole strength and scattering cross-section has been investigated in only one system, ultracold KRb in its absolute ground state. We now report evidence for inelastic dipole-dipole scattering in magnetically trapped metastable OH molecules under a polarizing electric field, with an apparent $d^2$ dependence rather than the $d^6$ law observed in optically trapped Krb.

$^1$We acknowledge funding from the AFOSR-MURI on Cold Molecules and the NSF.

$^2$M. H. is a National Research Council postdoctoral Fellow.

Thursday, June 7, 2012 8:00AM - 10:00AM —
Session M2 Strongly Interacting Fermions Grand Ballroom GF - Chair: Elise Novitski, Harvard University

8:00AM M2.00001 Compressibility of a Repulsive Fermi Gas of $^6$Li. MYOUNG-SUN HEO, YERYOUNG LEE, TOUT T. WANG, TIMUR M. RVACHOV, WOLFGANG KETTERLE, DAVID E. PRITCHARD, MIT — We studied the equilibrium properties of a two-component repulsive Fermi gas of $^6$Li by measuring the compressibility at various interaction strengths near a Feshbach resonance at 834G. The compressibility was extracted from in-trap atomic density profiles, and agrees with first order perturbation theory. Our experiment uses phase-contrast imaging to probe atomic clouds with large optical density, requiring compensation of dispersive effects. The feasibility window for such experiments is limited by decay to a near-resonant molecular bound state, and we explore the limits of this window by measuring decay rates at various interaction strengths.
8:12AM M2.00002 Revealing the Superfluid Lambda Transition in the Universal Thermodynamics of a Unitary Fermi Gas

MARK KU, ARIEL SOMMER, LAWRENCE CHEUK, MARTIN ZWIERLEIN, Department of Physics, MIT-Harvard Center for Ultracold Atoms, and Research Laboratory of Electronics, MIT, Cambridge, Massachusetts 02139, USA — We have observed the superfluid phase transition in a strongly interacting Fermi gas via high-precision measurements of the local compressibility, density and pressure down to near-zero entropy. We perform the measurements by in-situ imaging of ultracold $^{6}$Li at a Feshbach resonance. Our data completely determine the universal thermodynamics of strongly interacting fermions without any fit or external thermometer. The onset of superfluidity is observed in the compressibility, the chemical potential, the entropy, and the heat capacity. In particular, the heat capacity displays a characteristic lambda-like feature at the critical temperature of $T_c/T_F = 0.167$ (13). This is the first direct thermodynamic signature of the superfluid transition in a spin-balanced atomic Fermi gas. We measure the ground-state energy of the superfluid to be $3/5N_{EF}$, with $\xi = 0.376(4)$. The experimental results result from this theory, as well as connections with high temperature superconductors, will also be discussed.


8:24AM M2.00003 Pseudogap Effects in Rotating Fermi Gases from BCS to BEC

PETER SCHERPHELZ, VIVEK MISHRA, DAN WULIN, KATHRYN LEVIN, James Franck Institute and Department of Physics, University of Chicago, ATTIPAT RAJAGOPAL, Inspire Institute — In this talk we focus on pseudogap effects present in a rotating, ultracold Fermi gas as the system is tuned from a BCS regime to a BEC regime. Such pseudogap effects are expected to be present away from the BCS regime [1]. Importantly, no theory of rotating Fermi gases has yet incorporated these non-condensed pair effects. Our work is based on reformulating the Gor’kov equations, with the inclusion of a pseudogap, into a Landau level basis [2]. With this reformulation we can calculate quantities including the local density of states in the presence of vortices, and the upper critical rotation frequency. In a related way we present linear response calculations in the presence of a pseudogap which include the shear viscosity and moment of inertia. We show that finite size effects give rise to a non-classical moment of inertia even in the normal state. Testable predictions resulting from this theory, as well as connections with high temperature superconductors, will also be discussed.


8:36AM M2.00004 Repulsive polarons in a strongly interacting Fermi mixture

CHRISTOPH KOHSTALL, MATTEO ZACCANTI, MICHAEL JAG, ANDREAS TRENKWALDER, FLORIAN SCHRECK, RUDOLF GRIMM, Institut fur Quantenoptik und Quanteninformation (IQOQI), Austrian Academy of Sciences, 6020 Innsbruck, Austria, PETER MASSIGNAN, ICFO - Institut de Ciencies Fotoniques, Mediterranean Technology Park, 08860 Castelldefels (Barcelona), Spain, GEORG BRUUN, Department of Physics and Astronomy, University of Aarhus, 8000 Aarhus C, Denmark — Ultracold Fermi gases with tunable interactions represent a unique test bed to explore the many-body physics of strongly interacting quantum systems. In the past decade, experiments have mainly focused on the ground-state properties but metastable states in Fermi gases with strong repulsive interactions represent an exciting new frontier in the field. Here, we exploit radio-frequency spectroscopy to measure the complete excitation spectrum of fermionic $^{40}$K impurities resonantly interacting with a Fermi sea of $^{6}$Li atoms. In particular, we show that a well-defined quasiparticle exists for strongly repulsive interactions. For this “repulsive polaron” we measure its energy and its lifetime against decay. We also probe its coherence properties by measuring the quasiparticle residue. The results are well described by a theoretical approach that takes into account the finite effective range of the interaction in our system. We find that a non-zero range of the order of the interparticle spacing results in a substantial lifetime increase. This major benefit for the stability of the repulsive branch opens up new perspectives for investigating novel phenomena in metastable, repulsively interacting fermion systems.

8:48AM M2.00005 Dynamics of a Repulsive Fermi-Fermi Mixture

MARKO CETINA, MATTEO ZACCANTI, IQOQI, Austrian Acad. of Sciences, Innsbruck, MICHAEL JAG, CHRISTOPH KOHSTALL, IQOQI, Austrian Acad. of Sciences and Inst. for Exp. Physics, Univ. Innsbruck, ANDREAS TRENKWALDER, FLORIAN SCHRECK, IQOQI, Austrian Acad. of Sciences, Innsbruck, RUDOLF GRIMM, IQOQI, Austrian Acad. of Sciences and Inst. for Exp. Physics, Univ. Innsbruck, — There is a growing interest in repulsively interacting Fermi gas mixtures, which could enable investigations into correlated quantum systems. As repulsive interactions represent an exciting new frontier in the field, here, we exploit radio-frequency spectroscopy to measure the complete excitation spectrum of fermionic $^{40}$K impurities resonantly interacting with a Fermi sea of $^{6}$Li atoms. In particular, we show that a well-defined quasiparticle exists for strongly repulsive interactions. For this “repulsive polaron” we measure its energy and its lifetime against decay. We also probe its coherence properties by measuring the quasiparticle residue. The results are well described by a theoretical approach that takes into account the finite effective range of the interaction in our system. We find that a non-zero range of the order of the interparticle spacing results in a substantial lifetime increase. This major benefit for the stability of the repulsive branch opens up new perspectives for investigating novel phenomena in metastable, repulsively interacting fermion systems.


9:00AM M2.00006 Highly Polarized Fermi Gases across a Narrow Feshbach Resonance

RAN Qi, HUI ZHAI, Institute for Advanced Study, Tsinghua University — We address the phase of highly polarized Fermi gases across a narrow Feshbach resonance starting from the problem of a single down spin fermion immersed in a Fermi sea of up spins. Both polaron and pairing states are considered using the variational wave function approach, and we find that the polaron to pairing transition will take place at the BCS side of the resonance, strongly in contrast to a wide resonance where is located at the BEC side. However, we find that the critical strength of repulsive interaction between pairs above which the mixture of pairs and fermions will not phase separate. Therefore, a nearby a narrow resonance, it is quite likely that magnetism can coexist with s-wave BCS superfluidity at large Zeeman field, which is a remarkable property absent in conventional BCS superconductors (or fermion pair superfluids).

[1] This work is supported by Tsinghua University Initiative Scientific Research Program. Hui Zhai is supported by NSFC under Grant No. 11004118 and No. 11174176, and NKBRFSC under Grant No. 2011CB921500. Ran Qi is supported by NSFC under Grant No. 11104157.

9:12AM M2.00007 Towards Probing Homogeneous Strongly Interacting Fermi Gas

YOAV SAGI, TARA DRAKE, RABIN PAUDEL, JOHN STEWART, JOHN GÄEBLER, DEBORAH JIN, JILA, NIST and the University of Colorado — Superfluidity in strongly correlated matter is still an open question after many years of research. High Tc superconductors, for example, are known to exhibit a pseudo-gap phase above the critical temperature - a phase in which pairing exists in spite of the absence of long range order. An ultra-cold strongly interacting Fermi gas realizes a clean and controllable model system for studying these questions. It was shown recently that the normal state of a strongly interacting Fermi gas has a spectral behavior typical to a pseudo-gap phase [1]. One of the problems, however, which complicates the interpretation of these experiments is the inherent density inhomogeneity of the gas which arises due to the harmonic confinement. Here we present a technique to overcome this difficulty by spatially selecting only part of the cloud for interrogation while still retaining momentum resolution. We present measurements of the momentum distribution of a degenerate gas of 40K atoms revealing for the first time a truly sharp Fermi surface. We further extend the use of this technique to momentum resolved photo-emission spectroscopy and contact measurements.

9:24AM M2.00008 Realization of a Resonant Fermi Gas with a Large Effective Range, Y. ZHANG, E.L. HAZLETT, R.W. STITES, K.M. O’HARA, The Pennsylvania State University — We have measured the interaction energy and three-body recombination rate for a two-component Fermi gas near a narrow Feshbach resonance and found both to be strongly energy dependent. Even though the deBroglie wavelength greatly exceeds the van der Waals length scale for all cases studied, the behavior of the interaction energy as a function of temperature cannot be described by atoms interacting via a contact potential. Rather, energy dependent corrections beyond the scattering length approximation are required, indicating a resonance with an anomalously large effective range. This narrow resonance can be used to study strongly correlated Fermi gases that simultaneously have a sizeable effective range and a large scattering length. Resonant Fermi gases with energy-dependent two-body interactions accurately describe dilute neutron matter found at densities in the interior of neutron stars, may exhibit extraordinarily high superfluid critical temperatures, and could enable the observation of exotic new forms of matter such as the breached-pair superfluid phase in a polarized Fermi gas.

9:36AM M2.00009 Degeneracies in trapped two-component Fermi gases, D. BLUME, K.M. DAILY, D. RAKSHIT, Washington State University — We report on previously unobserved degeneracies in two-component equal-mass Fermi gases with zero-range interactions under isotropic harmonic confinement. Over the past 10 years or so, two-component Fermi gases with zero-range interactions have become a paradigm for modeling condensed matter systems, nuclear matter and neutron matter. We provide strong evidence that the eigen energies of the (3,1) system consisting of three spin-up atoms and one spin-down atom are degenerate with the eigen energies of the (2,2) system consisting of two spin-up atoms and two spin-down atoms for any s-wave scattering length $a_s$, including infinitely large, positive and negative $a_s$. Evidence for the existence of analogous degeneracies for larger systems is presented. The degeneracies evidenced in our study introduce a new class of highly-correlated systems for which such degeneracies, and thus an underlying symmetry, exist.

1We gratefully acknowledge support by the NSF and the ARO.

9:48AM M2.00010 Expansion of 1D polarized superfluids, HONG LU, L.O. BAKSMATY, Department of Physics and Astronomy, Rice University, C.J. BOLECH, Department of Physics, University of Cincinnati, HAN PU, Department of Physics and Astronomy, Rice University — We study the axial expansion dynamics of a one dimensional polarized Fermi gas after suddenly released from the confining trap. We perform our comparative studies using both mean-field Bogoliubov-de Gennes (BdG) and the numerically exact Time-Evolving Block Decimation (TEBD) methods. Our results show that strong spin density modulations, which are manifesting signatures of FFLO (Fulde-Ferrel-Larkin-Ovchinnikov) state and can be readily detected in experiment, develop during the expansion of the cloud, giving incontrovertible evidence to the FFLO state.

Thursday, June 7, 2012 8:00AM - 10:00AM — Session M3 Focus Session: Atomic Spectroscopy

8:00AM M3.00001 Resonant Auger Destruction in X-ray Photoionized Plasmas, DUANE LIEDAHL, Lawrence Livermore National Laboratory — Resonant Auger Destruction (RAD) is a hypothesized line-destruction mechanism, involving the interplay of atomic kinetics and radiation transport in X-ray photoionized plasmas, and has been invoked to explain the apparent absence of Kα satellite emission from L-shell ions in X-ray spectra of accretion-powered black holes. However, detections of this type of line emission in the X-ray spectra of neutron star accretors in our own Galaxy cast doubt on the efficacy of the RAD mechanism. Resolution of this problem, through atomic kinetics calculations, as well as direct laboratory measurements at the Sandia Z Facility, bears directly on interpretations of astrophysical X-ray spectra and accretion disk structure theory in the general relativistic domain.

8:30AM M3.00002 EUV Spectra of Xenon Observed with an Electron Beam Ion Trap, JOSEPH READER, DIMITRY OSIN, JOHN GILLASPY, YURI RALCHENKO, National Institute of Standards and Technology — Extreme ultraviolet spectra of highly charged xenon atoms were produced with an electron beam ion trap (EBIT) at the National Institute of Standards and Technology (NIST) and recorded with a flat-field grazing-incidence spectrometer. The wavelength range was 4.6 nm–16.4 nm. The beam energy varied from 1.5 to 6.5 keV to selectively enhance spectra of different ionization stages. Wavelength calibration was provided by spectra of highly-charged neon, argon, and iron. Identifications of strong n=4-n=4 and n=3-n=3 transitions from Zh-like xenon (24+) to Na-like xenon (43+) were determined with the aid of collisional-radiative modeling of the EBIT plasma. Good quantitative agreement between simulated and measured spectra was achieved. Some 56 lines were identified, 48 of which are new. Seven of these lines represent magnetic dipole transitions within the 3s^23p^6 ground configurations of these ions; one is an electric quadrupole transition within the 3s^23p^6 ground configuration of the Si-like ion.

2Supported in part by the Office of Fusion Energy Sciences of the U.S. Department of Energy

8:42AM M3.00003 Spectroscopy of Z-pinch plasmas: how atomic and plasma physics merge and unfold new applications, ALLA SAFRONOVA, Physics Department, University of Nevada, Reno, NV 89557 — Recent advances in theoretical and experimental work on plasma spectroscopy of Z-pinches are presented. We have shown that the University-scale Z-pinch generators are able to produce plasmas within a broad range of temperatures, densities, opacity, and radiative properties depending on the type, geometry, size, and mass of wire array loads and wire material. The full x-ray and EUV diagnostic set for detailed spatial and temporal monitoring of such a plasma together with relativistic atomic and molecular kinetics provides a unique platform for the study of atomic and plasma spectroscopy features and development of their applications. A variety of examples of K-shell low-Z (such as Mg and Al), L-shell mid-Z (such as Ni, Cu, and Ag), and M- and L-shell high-Z (W) will be considered and their specific features and applications to fusion and astrophysics will be highlighted.

2The author acknowledges contributions of V.L. Kantsyrev, U.I. SafroNova, M.E. Weller, G.C. Osborne, V.V. Shlyaptseva (all from UNR). The research was supported by DOE/NNSA under CA DE-FG52-06NA27588 and in part by DE-FG02-08ER54951.

9:12AM M3.00004 Synthetic X-Ray Spectra of Ar and Kr for Analysis of Data from the Z Machine at SNL, ARATI DASGUPTA, ROBERT CLARK, WARD THORNHILL, NICHOLAS OUARTE, JOHN APRUZESE, JOHN GIULIANI, Naval Research Laboratory, Washington, DC, BRENT JONES, DAVE AMPLEFORD, Sandia National Laboratories, Albuquerque, NM — A number of shots employing concentric gas puffs of Ar and Kr on the Sandia National Laboratories ZR accelerator are being planned, with the goal of optimizing K-shell yield. Experimental data from these implosions can provide a wealth of information about the ionization history of the plasma. Theoretical simulations using accurate atomic and hydrodynamics models will provide synthetic K- and L-shell spectra with which to compare and analyze the data. The presence and dynamics of bright K-shell emitting regions, which could possibly dominate the Kr K-shell yield, can be derived from radially and/or axially resolved, time-dependent spectra. By taking density and internal energy profiles near peak radiative power from the 2-D radiation hydrodynamics model, and post processing this data with a detailed multifrequency radiation transport scheme, the generation and evolution of these bright spots may be simulated. We will present synthetic spectra from the “bright” spots determined from the Ar and Kr 2D simulations, employing a recently developed non-LTE collisional-radiative spectroscopic model that combines the completeness of highly averaged Rydberg states models with the accuracy of detailed models for all important excited states.

1Work supported by DOE/NNSA
9:24AM M3.00005 Properties of Ni$^+$ from microwave spectroscopy of n=9 Rydberg levels of Nickel$^1$ , SHANNON WOODS, JULIE KEELE, CHRIS SMITH, STEPHEN LUNDEEN, Colorado State University — The microwave/RESIS method was used to determine the relative positions of 15 of the n=9 Rydberg levels of Nickel with L ≥ 6. Because the ground state of the Ni$^+$ ion is a $^2D_{5/2}$ level, each Rydberg level (n,L) splits into six eigenstates whose relative positions are determined by long-range e-Ni$^+$ interactions present in addition to the dominant Coulomb interaction. A previous study with the optical RESIS method determined these positions with precision of ±10 MHz.[1] Using the microwave/RESIS method improves that precision by a factor of 300, and leads to much improved determinations of the Ni$^+$ properties that control the long-range interactions.

1Supported by the Chemical Sciences, Geosciences, and Biosciences Division of the Office of Basic Energy Sciences, Office of Science, U.S. Dept. of Energy

9:36AM M3.00006 The Spectroscopy of Barium 6p$_{1/2}$nk Autoionizing States in Weak Electric Fields$^1$ , JIRAKAN NUNKAEW, THOMAS GALLAGHER, University of Virginia — We have measured the Ba 6p$_{1/2}$/n$k$, n = 17, 5 ≤ k ≤ n − 1 Stark autoionizing states’ photoexcitation cross sections and the autoionization rates in the low field regime by isolated core excitation (ICE) of the bound Ba$^{6+}$ 6s$n$k Stark states. During ICE the Rydberg electron remains in the same state ($nk$) while the ion core is excited from the ground state Ba$^+ 6s$ to the excited state Ba$^{6+}$ 6p$_{1/2}$. However, the change in the core yields the slight change in Coulomb potential and as the result the final wavefunction of electron is different from the initial wavefunction causing the shake up of the electron to other states. We have observed the shake up of electrons from $nk$ to $nk'$ states in the cross section. The observed cross section shows no transition of the electron from the $k$ state to the $k'$ states on the low energy side of $k$. This is due to the fact that in low field the bound and autoionizing Stark manifolds are incomplete; they are missing the low $\ell$ states with large quantum defects. Furthermore, they are different because they contain different numbers of $\ell$ states. The cross section can be theoretically described by treating the problem as discrete states embedded in one continuum state with finite lifetime.

This work has been supported by the U.S. Department of Energy

9:48AM M3.00007 Two-photon direct frequency comb spectroscopy of alkali atoms$^1$ , Khoa NGUYEN, San Jose State University, TRINITY PRADHANANGA, CHRISTOPHER PALM, California State University - East Bay, JASON STALKNER, Oberlin College, DEREK JACKSON KIMBALL, California State University - East Bay — We are using direct frequency comb spectroscopy to study transition frequencies and excited state hyperfine structure in potassium and rubidium using 2-photon transitions excited directly with the frequency-doubled output of a erbium fiber optical frequency comb. The frequency comb output is directed in two counterpropagating directions through a vapor cell containing the atomic vapor of interest. A pair of optical filters is used to select teeth of the comb in order to identify the transition wavelengths. A photomultiplier tube (PMT) measures fluorescence from a decay channel wavelength selected with another optical filter. Using different combinations of filters enables a wide range of transitions to be investigated. By scanning the repetition rate, a Doppler-free spectrum can be obtained enabling kHz-resolution spectral measurements. The thermal motion of the atoms in the vapor cell actually eliminates the need to fine-tune the offset frequency and repetition rate, alleviating a somewhat challenging requirement for spectroscopy of cold atoms. Our investigations are laying the groundwork for a long-term research program to use direct frequency comb spectroscopy to understand the complex spectra of rare-earth atoms.

1National Science Foundation Grant PHY-0958749

Thursday, June 7, 2012 8:00AM - 10:00AM — Session M4 Focus Session: Control of Molecular Dynamics — Garden 1-2 - Chair: Jonathan Wrubel, NIST

8:00AM M4.00001 Clocking Ultrafast Wave Packet Dynamics in Molecules through UV-induced Symmetry Breaking , Alicía PALACIOS, Universidad Autónoma de Madrid — A UV pump - UV probe scheme is used to trace the evolution of nuclear wave packets in excited molecular states. A direct map is obtained by analyzing the asymmetry of the electron angular distributions resulting from dissociative ionization. The asymmetry results from the coherent superposition of gerade and ungerade states of the remaining molecular ion in the region where the pumped nuclear wave packet is located. The variation of this asymmetry with the time delay between the pump and the probe pulses thus parallels that of the moving wave packet and, consequently, can be used to clock its field-free evolution. The hydrogen molecule is used as benchmark target, which is represented within the Born-Oppenheimer approximation including all electronic, including correlation, and nuclear degrees of freedom. Two identical UV pulses of a few fs of duration constitute a typical UV pump - UV probe scheme. The photon energy is chosen such that the pump pulse excites the system in the lowest single excited states of the neutral, and the probe pulse will ionize system. Two-photon ionization is the major channel leaving the ion in both its ground (1s2s ) and its first excited state (2p2s ). As expected, the proton kinetic energy release (KER) distributions vary with the time-delay between the pulses, but any signature of the pumped wave packet is hardly visible. However, the superposition of the gerade (1s2s ) and ungerade (2p2s ) electronic states induces an asymmetry in the angular distributions, whose dependence with time delay leads to a sharp image of the time evolution of the wave packet.

8:30AM M4.00002 Ultralong-range energy transfer by interatomic Coulombic decay in the giant helium dimer , Nicolas Sisourat, Université Pierre et Marie Curie, Paris, France — Interatomic (molecular) Coulombic decay (ICD) is an ultrafast non-radiative electronic decay process for excited atoms or molecules embedded in a chemical environment. Via ICD, the excited system can get rid of the excess energy, which is transferred to one of the neighbors and ionize it. It should be stressed that whereas the same excited atom when isolated relaxes only by emitting a photon in a time range of picoseconds to nanoseconds, ICD takes place in the femtosecond range. Thus, ICD is generally the most favorable of the excess energy, which is transferred to one of the neighbors and ionize it. It should be stressed that whereas the same excited atom when isolated relaxes

NGUYEN, San Jose State University, TRINITY PRADHANANGA, CHRISTOPHER PALM, California State University - East Bay, JASON STALKNER, Oberlin College, DEREK JACKSON KIMBALL, California State University - East Bay — We are using direct frequency comb spectroscopy to study transition frequencies and excited state hyperfine structure in potassium and rubidium using 2-photon transitions excited directly with the frequency-doubled output of a erbium fiber optical frequency comb. The frequency comb output is directed in two counterpropagating directions through a vapor cell containing the atomic vapor of interest. A pair of optical filters is used to select teeth of the comb in order to identify the transition wavelengths. A photomultiplier tube (PMT) measures fluorescence from a decay channel wavelength selected with another optical filter. Using different combinations of filters enables a wide range of transitions to be investigated. By scanning the repetition rate, a Doppler-free spectrum can be obtained enabling kHz-resolution spectral measurements. The thermal motion of the atoms in the vapor cell actually eliminates the need to fine-tune the offset frequency and repetition rate, alleviating a somewhat challenging requirement for spectroscopy of cold atoms. Our investigations are laying the groundwork for a long-term research program to use direct frequency comb spectroscopy to understand the complex spectra of rare-earth atoms.

1National Science Foundation Grant PHY-0958749
9:00AM M4.00003 Attosecond coherent control of C2D4 dynamics. PREDRAG RANITOVIC, CRAIG HOGLE, MARGARET MURNANE, HENRY KAPTEYN, University of Colorado - JILA — We employ ultrashort VUV pulses to initiate, and coherently control ultrafast dynamics and fragmentation of a C2D4 molecule by using an IR/VUV time-resolved attosecond COLTRIMS technique. A VUV frequency comb, containing the 5th, 7th, 9th, 11th, and 13th harmonic of the fundamental laser field (785 nm), was used to coherently populate several potential energy surfaces of a neutral C2D4 molecule, and a C2D4+ ion. By ionizing the neutral C2D4* molecule in a time-resolved fashion, using a strong (3x10^12 W/cm^2) laser field, we follow the fast relaxation of several excited states through conical intersections where the electronic excitation gets converted to vibrational motion. We investigate these dynamics on femtosecond and attosecond time scales. On the femtosecond time scale, we measure the decay constants of the fragments of interest (i.e. C2D4+, C2D3+, C2D2+, D+, and D2+), and find that the dynamics occur on the order of 50 fs after the VUV pump pulse. On the attosecond time scale, we find that we can control the fragmentation through interference of electron wave packets and by changing the laser intensities. We find that the absolute phases of the fragmentation yields are sensitive to the VUV/IR delay, and change as the molecule relaxes through conical intersections. The relaxation through conical intersections is a complex and important mechanism that we studied using an electron/ion 3D momentum imaging COLTRIMS technique. The ability to demonstrate coherent control of this relaxation process on an ultrafast time scale, is an important step towards control of chemical reactions.

9:12AM M4.00004 Control of Molecular Rotation with a Chiral Train of Ultrashort Pulses. SERGEY ZHDAHOVIC, ALEXANDER MILNER, CASEY BLOOMQUIST, The University of British Columbia, JOHANNES FLOSS, ILYA AVERBUKH, The Weizmann Institute of Science, JOHN HEPBURN, VALERY MILNER, The University of British Columbia — Trains of ultrashort laser pulses separated by the time of rotational revival (typically, tens of picoseconds) have been exploited for creating ensembles of aligned molecules. We introduce a chiral pulse train—a sequence of linearly polarized pulses with the polarization direction rotating from pulse to pulse by a controllable angle. The chirality of such a train, expressed through the period and direction of its polarization rotation, is used as a new control parameter for achieving selectivity and directionality of laser-induced rotational excitation. The method employs chiral trains with a large number of pulses separated on the time scale much shorter than the rotational revival (a few hundred femtosecond), enabling the use of conventional pulse shapers.

9:36AM M4.00006 Phase control with many cycle pulses in the absence of CEP stabilization. HYOUNGUK JANG, GUAN-YEU CHEN, WENDELL T. HILL III, Joint Quantum Institute and University of Maryland — Stabilization of the carrier envelope phase (CEP) of few-cycle pulses enhances our ability to control dynamics. When coupled with fixing the relative phase between two few-cycle pulses, control of molecular dynamics can be dramatic even when the pulse separation greatly exceeds the pulse widths. Here we present what we believe is the first demonstration of molecular dynamics control by a pair of many-cycle (t=50 fs) pulses separated by 3t with fixed relative CEP but in the absence of CEP stabilization of either pulse. In our experiment each pulse was intense enough to induce a Coulomb explosion of CO2 into doubly charged atomic ions. By monitoring the ions, which carry information about the molecular geometry at the time of the explosion, we were able to determine how the relative separation and phase of the two pulses influence how the second pulse interacts with the ensemble. Specifically, we modified the bond angle by about 33% and the strength of the second explosion by about a factor of 2.5. What makes our result noteworthy are (1) interference between the pulses plays no role and (2) coherence established by a long pulse influences how the second pulse interacts with the ensemble. Specifically, we modified the bond angle by about 33% and the strength of the second explosion by about a factor of 2.5. What makes our result noteworthy are (1) interference between the pulses plays no role and (2) coherence established by a long pulse is robust. Details of our experiment along with our result’s implication on evolutionary control mechanisms will be discussed.

9:48AM M4.00007 Understanding Intense Field Two-Color and Carrier-Envelope Phase Control. D. URSREY, B.D. ESRY, J.R. Macdonald Laboratory — The use of light to manipulate molecular dynamics and chemical reactions has become an increasingly important area of study in the past few decades. As intense laser pulses become more readily available, the ability to take advantage of multiphoton processes to enhance this control has become possible. Using tailored laser pulses, intense field control has already been demonstrated on a scale of about a factor of 2.5. What makes our result noteworthy are (1) interference between the pulses plays no role and (2) coherence established by a long pulse is robust. Details of our experiment along with our result’s implication on evolutionary control mechanisms will be discussed.

1 Supported by the Chemical Sciences, Geosciences and Biosciences Division, Office of Basic Energy Sciences, Office of Science, U.S. Department of Energy.

Thursday, June 7, 2012 8:00AM - 10:00AM — Session M5 Atoms and Cavities — Garden 3 - Chair: Murray Holland, University of Colorado at Boulder, JILA

8:00AM M5.00001 Generation of mesoscopic entangled states in a cavity coupled to an atomic ensemble. GOR NIKOGHOSYAN, University of Ulm, MICHAEL HARTMANN, Technische Universität München, MARTIN PLENIO, University of Ulm — The creation of mesoscopic entangled states is one of the fundamental challenges in quantum optics since they are very useful as resources for optical quantum information, quantum metrology, and super-precision lithography. In the present work (arXiv:1111.6047v1) we propose a novel system for the efficient production of optical NOON states based on the resonant interaction of a pair of quantized cavity modes with an ensemble of atoms. We show that in the strong-coupling regime the adiabatic evolution of the system tends to a limiting state that describes mesoscopic entanglement between photons and atoms which can easily be converted to a purely photonic or atomic NOON state. We also demonstrate the remarkable property that the efficiency of our scheme increases exponentially well with the cavity cooperativity factor, which gives efficient access to high number NOON states. The experimental feasibility of the scheme is discussed and its efficiency is demonstrated numerically.

1 Supported by CFI, BCKDF, NSERC, ISF.
8:12AM M5.00002 Atom-cavity system as a passive photon adder\footnote{Supported by NSF} , JULIO GEA-BANACLOCHE, University of Arkansas — A single three-level atom, in the $\Lambda$ configuraion, in an optical microcavity has been shown to have the potential to provide a totally passive photon-photon quantum logical gate [Koshino et al., Phys. Rev. A 82, 010301(R) (2010)]. Recently, the same system has also been shown to work as a “photon turnstile,” or photon subtractor, which could remove a single photon from an incident N-photon pulse by changing its polarization to an orthogonal state [Rosenblum et al., Phys. Rev. A 84, 033854 (2011)]. Here the possible performance of this system as a photon adder or subtractor will be analyzed, for different types of intial states, paying special attention to spectral entanglement effects and pulse reshaping.

8:24AM M5.00003 Photon blockade with a four-level atom coupled to a microcavity , MICHAL BAJCSY, ARKA MAJUMDAR, JELENA VUCKOVIC, Ginzioni Laboratory, Stanford University — We study the photon blockade phenomenon in a cavity containing a single four-level atom, starting with an idealized spacing of the energy levels in such atom. We show that while photon blockade in a cavity containing a single-level atom (Raman blockade) becomes observable even in the absence of strong coupling when a four-level atom is used. The four-level atom outperforms the two-level atom also in the strongly coupled regime, as well as in the case when the spacing of the energy levels in the four-level atom becomes non-ideal. Finally, we show than that the mode volume and quality factors currently available in semiconductor optical microcavities, photon blockade should be achievable with alkali atoms coupled to such cavities.

8:36AM M5.00004 Collective state signatures in quantum correlations of Cavity QED\footnote{Work supported by CONACYT, NSF and the Marsden Fund of the RSNZ.} , PABLO BARBERIS-BLOSTEIN, IIMAS- Universidad Nacional Autonoma de Mexico, HOWARD CARMICHAEL, University of Auckland, LUIS OROZCO, University of Maryland — The correlation function of spontaneous emission from of a continuously driven atomic ensemble inside a two-mode optical cavity (vertical and horizontal polarizations) exhibits a single atom contribution when one and the same atom executes Raman transitions to scatter two orthogonally polarized photons in sequence. This single-atom contribution can show photon anti-bunching, the widely understood non-classical signature of single-atom emission. If, on the other hand, there is more than one atom present at the moment the first photon is detected, the atomic ensemble must collapse to a collective state, since there is no way to know which atom emitted the photon. The collective state makes a new contribution to the correlation function and can generate collective photon anti-bunching (interference between anti-bunched probability amplitudes for a second photon emission). We discuss how to detect this collective state through measuring correlation functions and the decoherence mechanisms that transform the collective atomic state into a separable state.

9:00AM M5.00006 Control of Photon Fock States in an Optical Cavity , BYRON LOWRY, BERKRET BERHANE, SERGEY DRAKUNOV, Embry-Riddle Aeronautical University — The ability to control quantum mechanical states is an essential requirement for many experiments in fundamental quantum mechanics and applications in quantum information system. In this paper we derive the equation governing the dynamics of a single, two state, non-spontaneously emitting atom in a lossless cavity interacting with a single mode. Two different control methods are discussed and the controllability of the system is investigated for each method. The first method involves varying the coupling constant on the electric field and laser interaction. The second involves pumping or bleaching the system using atoms in the excited and grounds states respectively. A feasibility argument was made for the controllability of the system under those conditions. The dynamics of the system are then shown through arbitrary change of the control variables.

9:12AM M5.00007 ABSTRACT WITHDRAWN —

9:24AM M5.00008 Dissipative Preparation of Squeezing of a Collective Atomic Spin in a Cavity , JOHANNES OTTERBACH, EMANUELE DALLA TORRE, Harvard University, VLADAN VULETIC, Massachusetts Institute of Technology, MIKHAIL LUKIN, Harvard University — Spin squeezed states have attracted substantial interest over the last decades from fundamental and application points of view to study many-body entanglement and improve high-precision spectroscopy. One limiting factor for squeezing is the coupling to the environment which usually has detrimental effects on the generation and entanglement fidelity of these states. Here we present a scheme for the deterministic generation of spin squeezed states in coherently driven atomic ensemble of effective spin-1/2 particles collectively interacting with a strongly decaying cavity mode, thus turning dissipation into a resource for entanglement. We show that there exists an optimal regime of the decay rate which exhibits squeezing bounded only by the Heisenberg limit and calculate the timescale to reach this state. Upon taking spontaneous atomic scattering into account we determine the general scaling of the squeezing as a function of the collective atom-photon coupling and the cavity and atomic decay rates showing an improvement compared to the preparation schemes based on unitary time evolution.

9:36AM M5.00009 A Superradiant Raman Laser with < 1 Intracavity Photons , JUSTIN BOHNET, ZILOG CHEN, JOSHUA WEINER, DOMINIC MEISER, MURRAY HOLLAND, JAMES THOMPSON, University of Colorado at Boulder, JILA — We have demonstrated a cold-atom Raman laser operating deep in the bad-cavity (or superradiant) regime, where the atomic linewidth is much narrower than the cavity linewidth. The collective light-atom excitation is stored predominately in the atoms, with intracavity photon number as low as 0.2 photons. The low intracavity photon number isolates the collective atomic dipole from the environment — a possible future method for overcoming thermal fluctuations of cavity mirrors that presently limit the stability of state-of-the-art lasers.

This laser linewidth is measured to be $> 10^3$ below the Schawlow-Townes linewidth that normally applies to good-cavity optical lasers, as well as below single particle linewidths. Our system confirms key predictions that may enable the creation of superradiant lasers using highly forbidden atomic transitions that would have earth-sun coherence lengths, might improve optical atomic clocks by orders of magnitudes, and would contribute to searches for new physics beyond the standard model.
Shorter correlation time scale for a denser atomic ensemble implies a broader spectral window required to store or retrieve the idler pulse. We apply the positive-P phase space method to investigate the dynamics of the atoms and counter-propagating emissions in the four-wave mixing condition. The light field intensities are calculated, and the signal-idler correlation function is studied for different optical depths of the atomic ensemble.

We study the excitation, interaction and retrieval of collective excitations (spin waves) of Rydberg levels in large, optically thick atomic ensembles. Rather than assuming a Rydberg blockade mechanism, multiple Rydberg level excitations are allowed to mutually interact and dephase. We describe how dipole-dipole interactions destroy the correlations between spin waves leading to isolation and manipulation of individual excitations. Optical retrieval in a phase-matched direction shows the suppression of correlation. The dephasing process is suitable for the fast creation of high quality single photons with maximum efficiency $1/e$. Individual excitations can be stored in separate weakly-interacting Rydberg levels and later entangled by applying a dedicated dephasing scheme. This mechanism is shown to have a favorable, approximately exponential, scaling. Strong dipole-dipole interactions are required to speed up the protocol. This can be accomplished by mixing various opposite-parity Rydberg levels with a microwave field. This resonant coupling $(ns + np → ns + np)$ extends the $1/r^3$ interaction over the whole ensemble, while short range Van der Waals channels $(ns + ns → np + (n−1)p)$ decay as $1/r^6$.

We acknowledge financial support from NSF and AFOSR.

8:00AM M6.00001 Dynamics of Rydberg spin waves in atomic ensembles, ALEXEY GORSHKOV, California Institute of Technology, REJISH NATH, University of Innsbruck, JOHANNES OTTERBACH, Harvard University, MICHAEL FLEISCHHAUER, Technische Universitat Kaiserslautern, MIKHAIL LUKIN, Harvard University, THOMAS POHL, Max Planck Institute for the Physics of Complex Systems — We study the theory of light propagation under the conditions of electromagnetically induced transparency in systems involving strongly interacting Rydberg states. Taking into account the quantum nature of light, we compute the propagation of an arbitrary input pulse in the limit of strong Rydberg-Rydberg interactions. We also solve the case of a few-photon pulse for arbitrary Rydberg-Rydberg interaction strengths $[PRL 107, 133602 (2011)]$. We show that this system can be used for the generation of nonclassical states of light including single photons and trains of single photons with an avoided level between them, for implementing photon-photon gates, as well as for studying many-body phenomena with strongly correlated photons.

8:00AM M6.00002 Dissipative Many-body Quantum Optics in Rydberg Media, ALEXEY GORSHKOV, California Institute of Technology, REJISH NATH, University of Innsbruck, JOHANNES OTTERBACH, Harvard University, MICHAEL FLEISCHHAUER, Technische Universitat Kaiserslautern, MIKHAIL LUKIN, Harvard University, THOMAS POHL, Max Planck Institute for the Physics of Complex Systems — We study the theory of light propagation under the conditions of electromagnetically induced transparency in systems involving strongly interacting Rydberg states. Taking into account the quantum nature of light, we compute the propagation of an arbitrary input pulse in the limit of strong Rydberg-Rydberg interactions. We also solve the case of a few-photon pulse for arbitrary Rydberg-Rydberg interaction strengths $[PRL 107, 133602 (2011)]$. We show that this system can be used for the generation of nonclassical states of light including single photons and trains of single photons with an avoided level between them, for implementing photon-photon gates, as well as for studying many-body phenomena with strongly correlated photons.

8:24AM M6.00003 Few-photon optical nonlinearity using cold Rydberg atoms, THIBAULT PEYRONEL, MIT, OFER FIRSTENBERG, Harvard University, QIYU LIANG, VLADAN VULETIC, MIT — Effects of the Rydberg blockade in cold atomic clouds have been intensively explored over the last few years. Optical fields can be coherently and mapped onto atomic states with a Rydberg component using EIT techniques. As the dipole-dipole interaction between Rydberg atoms prevents several polaritons from propagating simultaneously within a Rydberg volume, it gives rise to strong non-linearities which are mapped back on the probe optical field. We aim at bringing the Rydberg-EIT nonlinear features into the single-photon regime in order to produce non-classical highly correlated states of light. Rubidium atoms are loaded in a far off-resonant (1064nm) optical dipole trap, where densities are typically large enough to reach high optical depths within a single blockade volume. In this regime, the dephasing of photon-photon correlation function is expected to exhibit highly non-classical behavior, corresponding to trains of spatially separated single-photons. Moreover, EIT techniques together with a high-resolution imaging system allow the observation of Rydberg excitations in the quasi-1D configuration, and should pave the way to in-situ monitoring of strongly correlated many-body states such as the crystallisation of Rydberg atoms.

8:36AM M6.00004 Steady-state antiferromagnetic order and quasi-crystalisation of Rydberg excitations in optically driven atomic ensembles, MICHAEL HOENING, Department of Physics and Research Center OPTIMAS, University of Kaiserslautern, Germany, DAVID PETROSYAN, Institute of Electronic Structure and Laser - FORTH, 71110 Heraklion, Crete, Greece, MICHAEL FLEISCHHAUER, Department of Physics and Research Center OPTIMAS, University of Kaiserslautern, Germany — We study resonant optical excitations of spatially frozen atoms in 1D trapping potentials and lattices to strongly-interacting Rydberg states. In the steady-state of strong uniform driving, correlations of Rydberg excitation probabilities exhibit exponentially decaying spatial oscillations with the period approaching one collective excitation per Rydberg blockade distance (superatom). For few atoms per blockade distance, the system is well described by a rate equation model with hard sphere superatoms. For higher densities approaching a continuous limit, we find via numerical simulations that the superatoms develop soft boundaries. For the case of an additional lattice trap, we derive an effective master equation with non-local damping. We give analytic expressions for the many-body steady state and the correlation length of the Rydberg quasi-crystal or antiferromagnetic order and discuss conditions when it can approach infinity.

8:48AM M6.00005 Homonuclear cesium Rydberg molecules, SETH RITTENHOUSE, HOSSEIN SADEGHPOUR, ITAMP, Harvard-Smithsonian Center for Astrophysics, Cambridge, MA 02138 — Over a decade ago, a new type of molecule was predicted consisting of a highly excited Rydberg atom and a ground state atom within the Rydberg electron orbit. More recently these molecules were observed spectriscopically in s-wave dominated states—redshifted from atomic lines— in an ultra-cold gas of rubidium atoms. Later, it was shown that an energetically nearby set of nearly degenerate states admixes slightly into the electronic ground state resulting in a sizable permanent electric dipole moment. In cesium atoms, the analysis and prediction of vibrationally bound states is complicated by a near degeneracy between the $ns$ Rydberg state and the degenerate higher angular momentum states. The resulting Born-Oppenheimer (BO) potentials show that a set of bound states above the $ns$ threshold might form. In this talk, we present the predicted BO potentials for cesium Rydberg molecules and examine the metastable vibrational states.

This work was supported by an NSF grant to ITAMP at Harvard University and the Smithsonian Astrophysical Observatory.
9:00AM M6.00006 Ultra-long-range Cs Trilobite Molecules in a Crossed 1064 nm Dipole Trap . JONATHAN TALLANT, DONALD BOOTH, JAMES SHAFFER, University of Oklahoma — Ultra-long-range molecules involving Rydberg atoms have been shown to exist in several different experimental regimes. Rydberg atom-Rydberg atom molecules have been created in the presence of bond-stabilizing electric fields at relatively low densities, \( \lesssim 10^{16} \text{ cm}^{-3} \). In a crossed dipole trap, where the density is \( \sim 3 \) orders of magnitude higher, new types of Rydberg atom molecules may be created. In particular, a novel bonding mechanism arises from the low energy scattering of a Rydberg atom electron off of a ground state atom. These so-called “trilobite” molecules can be in low or high angular momentum states. We present experimental spectra of low and high angular momentum trilobite molecules in a Cs crossed dipole trap.

9:12AM M6.00007 Theoretical Dynamics of Heavy Rydberg States in Rb\(_2\) . ADAM KIRRANDE, H.R. SADEGHPOUR, ITAMP, Harvard-Smithsonian CFA, Cambridge, MA 02138, USA — Rydberg states, characterized by long-range Coulomb interactions, are normally associated with states consisting of an electron and a positively charged atomic or molecular ion, but can also occur as vibrational states in ionic bonds between atoms. In such heavy Rydberg states, the light electron is replaced by a much heavier negative ion. Compared to normal vibrational states these have unusual properties, including extremely large internuclear distances, large dipole moments, and an infinity of states below the ion-pair dissociation limit. Ion-pair states are difficult to observe in experiments, but recently detailed spectra of heavy Rydberg states in \( \text{H}_2 \) and \( \text{Cl}_2 \) have been reported. We collaborate with the experimental groups of E. E. Eyler and P. Gould (UConn) to find heavy Rydberg states in \( \text{Rb}_2 \). Recent theoretical results are presented, and we discuss the potential application of \( \text{Rb}_2 \) heavy Rydberg states in cold matter physics.

9:24AM M6.00008 Anisotropic Rydberg Interactions . DONALD BOOTH, JONATHAN TALLANT, ARNE SCHWETTMANN, JAMES SHAFFER, University of Oklahoma — Strongly-correlated systems with anisotropic interactions are a field of increasing interest in atomic physics. Unique phases of matter can form in these systems, such as supersolids and checkerboard phases. One promising system for studying these phases is an ultracold Rydberg gas. In a small applied electric field, the interactions between Rydberg atoms are anisotropic as the electric field polarizes the atoms. The anisotropy can be significant compared to the other interactions between the atoms and can be used, in principle, to dress ground state atoms in a trap. We present a theoretical calculation of the anisotropic Rydberg atom interactions of the \( 81D_{5/2} \), \( 90D_{5/2} \), and \( 50D_{5/2} \) states at various electric fields to investigate some aspects of the practicality of these ideas.

9:36AM M6.00009 Exciting Rydberg atom superposition states for control of resonant energy exchange\(^1\) . DONALD P. FAHEY, MICHAEL W. NOEL, Bryn Mawr College, THOMAS CARROLL, Ursinus College — Pairs of ultracold highly excited atoms can exchange energy over long distances through a dipole-dipole coupling. Application of a dc electric field makes it possible to tune these energy exchange processes into resonance via the Stark effect. Our experimental system allows individual \( |m_j| \) sublevels of Rb Rydberg states to be excited, and then tuned into a dipole-dipole resonance. We can also excite coherently superpositions of these states, which can be used to control this energy exchange. We present experiments that investigate how this energy exchange proceeds for different initial \( |m_j| \) state preparations.

\( ^1 \)This material is based upon work supported by the National Science Foundation under Grant No. 0653544 and the Extreme Science and Engineering Discovery Environment (XSEDE), which is supported by National Science Foundation grant number OCI-1053575.

9:48AM M6.00010 Polarization Dependent Dark Resonances in Electromagnetically Induced Transparency with Rydberg Atoms . JONATHON SEDLACEK, ARNE SCHWETTMANN, HAOQUAN FAN, JAMES SHAFFER, University of Oklahoma — We present an experimental study of optical pumping into different hyperfine Rydberg states in a Rb cell using a 4 level EIT scheme. The lower three levels are coupled together using lasers, while microwaves couple the two upper Rydberg states together. With different laser and microwave polarizations, different hyperfine states will be coupled together resulting in polarization dependent dark resonances. The experimental results match our theoretical calculations using the complete 4 level system. This technique can also be used for quantum assisted sensing of the amplitude and polarization of the electric field that is coupling the Rydberg states together.

Thursday, June 7, 2012 8:00AM - 10:00AM —
Session M7 Undergraduate Session Terrace - Chair: Charles Conover, Colby College

8:00AM M7.00001 LeRoy Apker Award Lecture: Strong-field dissociation dynamics of NO\(^{2+}\): A multiphoton electronic or vibrational excitation\(^2\) . BETHANY JOCHIM\(^2\), J. R. Macdonald Laboratory, Department of Physics, Kansas State University, Manhattan, KS 66506 — A 3-D momentum imaging technique is employed to study intense ultrafast laser-induced dissociation of a metastable NO\(^{2+}\) beam. We focus on \( N^1 + O^5\) coincidences and explore possible dissociation pathways using estimates of the initial vibrational population and transition rates between the \( X^2\Sigma^+ \) and \( A^2\Pi \) states together with our measured kinetic energy release and angular distribution spectra. Our analysis suggests that lower intensity pulses (\( <10^{15} \text{ W/cm}^2 \)) drive perpendicular transitions between these states. Higher intensity pulses (\( >10^{16} \text{ W/cm}^2 \)), on the other hand, yield a prominent contribution from molecules breaking parallel to the polarization. An intriguing possibility is that this feature is due to a two photon permanent dipole transition to the vibrational continuum of the \( X^2\Sigma^+ \) state, i.e., a multiphoton vibrational excitation involving only the electronic ground state. The results of our time-dependent Schrödinger equation calculations comparing the probabilities of this type of pathway and competing electronic transitions will be presented.

\(^1\)Supported by the Chemical Sciences, Geosciences and Biosciences Division, Office of Basic Energy Sciences, Office of Science, U.S. Department of Energy. BJ acknowledges NSF grant PHY-0851599, and EW and BJ acknowledge NSF grant PHY-0969687.

\(^2\)Co-authors: M. Zohrabi, B. Gaire, U. Ablikim, K.D. Carnes, F. Anis, B.D. Esry, I. Ben-Itzhak, Kansas State University; E. Wells, Augustana College-Sioux Falls, SD; T. Uhlíkoviç, Institute of Chemical Technology, Czech Republic.

8:30AM M7.00002 Calculations of Hyperfine Antihydrogen Spectroscopy . PATRICK DONNAN, FRANCIS ROBICHEAUX, Auburn University — In 2011, the Antihydrogen Laser Physics Apparatus (ALPHA) Collaboration reported trapped antihydrogen atoms in the ground state[2] placing spectroscopic measurements of antihydrogen within experimental reach. We present simulations for hyperfine spectroscopy of antihydrogen contained in a Penning-Malmberg trap. The trap used in the simulations approximates the magnetic fields present in the ALPHA trap. Using the Landau-Zener approximation we compute the transition rates for antihydrogen from a trapped, low-field-seeking state to an untrapped, high-field-seeking state when resonant microwaves are applied. We present results for each of the two low-field-seeking states. We show that resonances occur near the trap minimum, and that the rates are sufficiently high to distinguish spin-flipped antihydrogen atoms from cosmic noise counts. We determine that a pulsed application of the microwaves is optimal and show the feasibility of microwave spectroscopy, which can also serve as a detection tool for trapped antihydrogen atoms. We also report on the feasibility of laser cooling antihydrogen for future spectroscopic measurements.

8:45AM M7.00003 Empirical Model for Total Internal Reflection (TIR) from Highly Turbid Media

KASHIKA GOYAL, MIAO DONG, BRADLEY WORTH, LALIT BALI, SAMIR BALI, Department of Physics, Miami University — Recently we introduced a new empirical model for total internal reflection (TIR) from a highly turbid medium [W. Calhoun, et al., Opt. Lett. 36, 1224-1226 (2010); ibid 36, 3172 (2011)]. The key feature of our model is that it incorporates into Fresnel theory the effect of angle-dependent penetration of the incident light into the medium. Here we show that the TIR data is, for the first time, well described by a model which has no extraneous fitting parameters. As a further check we use our model to extract the particle size for a highly turbid aqueous solution of monodisperse polystyrene microspheres of known size. Next we apply our model to a first in-situ measurement of average particle size in a widely used intravenous human nutrient.

Financial support from Petroleum Research Fund and Dillon-Kane LLC is gratefully acknowledged.

9:00AM M7.00004 Modeling Quantum Spin Dynamics in an Ultracold Gas

B.J. LAND, C.D. HAMLEY, C.S. GERVING, T.M. HOANG, M.L.B. ANQUEZ, M.S. CHAPMAN, Georgia Institute of Technology — A recent experiment in our lab focuses on investigating spin dynamics in the quantum regime, where mean field approaches fail. Previous theoretical models for the quantum dynamical evolution of a spin-1 Bose-Einstein condensate do not include the effects of atomic loss that is unavoidable in experiment. Here, we present results of different loss models including a fully quantum calculation of this complicated many body system using a Monte-Carlo approach. We compare the results of these methods to recent experimental measurements and obtain good agreement.

9:15AM M7.00005 Revisiting Pound-Drever-Hall frequency stabilization in the radio-frequency domain

CHELSEA LIEKHUS-SCHMALTZ, JAMES MARTIN, University of Waterloo — By revisiting Pound-Drever-Hall locking as a method for stabilizing rf oscillators, we have developed two new laser stabilization methods and an undergraduate lab exploring the technique. In the first stabilization scheme a tunable rf source (stabilized using Pound-Drever-Hall locking) phase modulates an injection locked diode laser. The length of an optical cavity can be locked to one of the adjustable sidebands of this laser, which stabilizes a second laser [1]. The second scheme is a version of rf beat note locking with one frequency modulated laser. The rf heterodyne signal can be mixed with an rf tunable source and a Pound-Drever-Hall error signal generated from reflection off an rf cavity can stabilize one of the original lasers. By changing the tunable frequency, the locked laser frequency can be changed. The stability and tunability of both stabilization methods are established by observing the hyperfine components of the $^{87}$Rb $5P_{3/2} - 5D_{3/2}$ transition in a vapor cell. Finally, an undergraduate lab [2] was developed that consists of locking a voltage-controlled-oscillator to a copper resonating cavity using Pound-Drever-Hall locking. By working at lower frequencies, the technique can be understood in more detail.

[1] arxiv/1109.0338

9:30AM M7.00006 A new $^{3}$He-$^{129}$Xe Co-magnetometer using a Ramsey measurement sequence and Rb-K magnetometer for spin detection

AARON KABCENELL, Princeton University, IANNIS KOMINIS, University of Crete, MICHAEL ROMALIS, Princeton University — Noble gas co-magnetometers have been used for many precision measurements, but their sensitivity is still very far from fundamental limits. We are exploring a new approach for operation of a $^{3}$He-$^{129}$Xe co-magnetometer that uses a sensitive Rb-K magnetometer as a spin detector. By placing the noble gas atoms inside the magnetometer cell we can increase their magnetic signal using the Fermi-contact interaction, representing a gain of nearly 500 for $^{29}$Xe, and achieve nearly quantum-noise limited detection of nuclear spins. In order to take advantage of the long coherence times of $^{3}$He and $^{29}$Xe, the precession measurement is based on the Ramsey method of separated oscillatory fields and will be performed in an alkali-metal-free volume. The gas is then transported to the spin detector using techniques developed for remote NMR detection. The sensitivity of this approach is estimated to be on the order of $10^{-13}$ Hz/day$^1/2$, making it several orders of magnitude more sensitive than the best existing co-magnetometers. We are currently performing tests of the Ramsey measurement method and the sensitivity of the spin detector.

Supported by NSF PHY-0969862.

9:45AM M7.00007 Investigating Electronic Properties and Bound-Bound Transitions in the Negative Ion of Lanthanum

DANIEL MATYAS, ADAM LEBOVITZ, KIRSTEN LIEBL, DANIEL GIBSON, WALTER WESLEY, Denison University — The electronic structure and correlation of the electrons in the negative ion of lanthanum have been investigated using laser photodetachment spectroscopy. The ions were photodetached by an infrared laser beam that crossed the ion beam path and the resulting neutral atom signal was measured as the photon energy was scanned. Ten resonance peaks were observed between 0.290 eV - 0.510 eV. Some resonance peaks are identified as being due to $^{131}$La, $^{133}$La, and $^{134}$La, and tunability of both stabilization methods are established by observing the hyperfine components of the $^{131}$La $5P_{3/2} - 5D_{3/2}$ transition in a vapor cell. Finally, an undergraduate lab [2] was developed that consists of locking a voltage-controlled-oscillator to a copper resonating cavity using Pound-Drever-Hall locking. By working at lower frequencies, the technique can be understood in more detail.


Thursday, June 7, 2012 10:30AM - 12:30PM – Session N2 Optical Lattices

Grand Ballroom GF - Chair: Ken O’Hara, Penn State University

10:30AM N2.00001 Investigation of the Fermi-Hubbard model with $^{6}$Li in an optical lattice

RUSSELL A. HART, PEDRO M. DUARTE, TSÜNG-LIN YANG, RANDY G. HULET, Rice University — We present our results on investigation of the physics of the Fermi-Hubbard model using an ultracold gas of $^{6}$Li loaded into an optical lattice. We use all-optical methods to efficiently cool and load the lattice beginning with laser cooling on the $2S_{1/2} - 2P_{3/2}$ transition and then further cooling using the narrow $2S_{1/2} - 3P_{2/3} - T$ transition to $T \sim 59 \mu K$. The second stage of laser cooling greatly enhances loading to an optical dipole trap where a two spin space mixture of atoms is evaporatively cooled to degeneracy. We then adiabatically load $\sim 10^9$ degenerate fermions into a 3D optical lattice formed by three orthogonal standing waves of 1064 nm light. Overlapped with each of the three lattice beams is a non-retroreflected beam at 532 nm. This light cancels the harmonic trapping caused by the lattice beams, which extends the number of lattice sites over which a Néel phase can exist and facilitates evaporative cooling in the lattice. We investigate the possibility of observing antiferromagnetic ordering of spins in the lattice using Bragg scattering of light.

Supported by NSF, ONR, DARPA, and the Welch Foundation.


10:42AM N2.00002 Dual Mott Insulator in a Spin-Dependent Optical Lattice, HIROKAZU MIYAKE, GEORGIOS SIVILOGLOU, COLIN KENNEDY, MIT, DAVID WELD, University of California, Santa Barbara, DAVID PRITCHARD, WOLFGANG KETTERLE, MIT — A major goal of the field of ultracold atoms is the realization of quantum magnetism. It has been theoretically proposed that for a two-component system in an optical lattice, one can emulate the Heisenberg Hamiltonian and observe phases such as XY-ferromagnetism and anti-ferromagnetism by controlling the spin-exchange constants. Towards this goal, we have developed a spin-dependent optical lattice for bosonic $^{87}$Rb atoms that allows us to tune the inter-species interaction energy. In particular, we have studied its effect on the superfluid-to-Mott insulator transition.

10:54AM N2.00003 First order SF-MI transition in the Bose-Hubbard model with tunable three-body onsite interaction, BARBARA CAPOGROSSO-SANSONE, University of Oklahoma, ARCHAVAN SAFAVI-NAINI, Harvard/MIT CUA, JAVIER VON STECHER, JILA, SETH RITTENHOUSE, ITAMP — Ultra-cold atoms in optical lattices have allowed for exploration of quantum effects beyond the superfluid to Mott insulator transition. Moreover, many-body interactions might give rise to new intriguing phenomena. In this work we study how the presence of an onsite, tunable, 3-body interaction term affects the many-body physics of the two-dimensional Bose Hubbard model. The 3-body interaction can be tuned by coupling the triply occupied states to a trapped universal trimer. We present mean field results which we compare with Monte Carlo calculations. We find that, as the 3-body interaction strength increases, the $n = 3$ Mott lobe grows larger at the expense of the neighboring lobes and phase transitions from superfluid to Mott insulator become of first order. Our studies at finite temperature show that these transitions remains of first order at temperatures of order of the hopping.

11:06AM N2.00004 Degenerate gases of strontium in optical lattices, SIMON STELLMER, BENJAMIN PASQUIOU, RUDOLF GRIMM, FLORIAN SCHRECK, Institut für Quantenoptik und Quanteninformation (IQOQI) — Ultracold strontium atoms are subject to active research due to properties not present for alkali atoms. Our recent achievements of quantum degeneracy of all existing bosonic and fermionic isotopes allow for a wide variety of experiments. Insensitivity to external fluctuations, long lifetime metastable states, and decoupling of the nuclear spin from the electronic state make strontium an ideal candidate for quantum computation processes. This system can also be used to implement quantum simulation of many-body effects: strontium atoms exhibit SU($N$) symmetry, as their collisional properties are spin-independent, and can therefore be used to study SU($N$) magnetism effects, such as the implementation of the Kondo lattice model or the observation of spin liquids. Here we report on the improved production of degenerate gases of all strontium isotopes. Moreover, we report on the creation of various doubly-degenerate Bose-Bose and Bose-Fermi mixtures of strontium isotopes. We present the adiabatic loading of strontium BEC in a 3D optical lattice into the Mott insulator regime. We also report on the loading of degenerate multi-component Fermi seas of up to 10 spin states in optical lattices, and observe the appearance of the Mott insulator regime for these systems.

11:18AM N2.00005 Reservoir-assisted band decay of ultracold atoms in a spin-dependent optical lattice, DAVID CHEN, DAVID MCKAY, CAROLYN MELDGIN, BRIAN DEMARCO, University of Illinois at Urbana Champaign — We report measurements of reservoir-assisted decay of atoms in excited bands in a cubic, spin-dependent optical lattice. We adiabatically load a $^{87}$Rb BEC in a mixture of $\text{mF}=0$ and $\text{mF}=\pm 1$ states into a 3D lattice. Atoms in the $\text{mF}=\pm 1$ state experience a strong lattice potential. On the contrary, atoms in the $\text{mF}=0$ state form a harmonically trapped superfluid reservoir since they do not interact with the lattice. We transfer atoms in the $\text{mF}=\pm 1$ state to the first excited band using stimulated Raman transitions, and we measure the decay rate to the ground band induced by collisions with the reservoir.

11:30AM N2.00006 Bose-Einstein Condensation in the second band of an optical lattice, a tight binding analysis and numerical estimation of its formation and decay, SAURABH PAUL, EITE TIESINGA, Joint Quantum Institute — We investigate the formation of a Bose Einstein condensate in the p-band of a double well optical lattice [1]. The lattice traps the atoms in two dimensions while confinement in the third direction is provided by a weak harmonic trap. We estimate the band structure using a tight binding (TB) model, using local simple harmonic oscillator functions. We are interested in the case when the ground s-orbital of shallow wells and the excited p-orbital of adjacent deep wells is tuned to resonance, by varying the onsite energy real time. A numerical estimate of the band structure using a plane wave basis, and comparison of the tunneling parameters with that of the TB model reveals that the TB model is not a good approximation for higher bands. In the TB limit, we estimate the life time of the condensate, which is mainly dominated by a two body collision aided decay process to the ground band. Numerically, we find corrections to this, where simultaneous transitions to the ground and an excited band also contributes to the decay of the condensate.


11:42AM N2.00007 Sub-wavelength Resonance Imaging and Robust Addressing of Atoms in an Optical Lattice, ENRIQUE MONTANO, JAE HOON LEE, POUL JESSEN, University of Arizona, IVAN DEUTSCH, University of New Mexico — We demonstrate a resonance imaging protocol for optical lattices that enables robust preparation and single qubit addressing of atoms with sub-wavelength resolution in 1D. Our setup consists of a 3D optical lattice, and a superimposed long-period 1D “superlattice” that creates a position dependent shift of the transition frequency between two spin states in the ground manifold. We show that isolated planes of atoms can be prepared by flipping resonant spins with a microwave pulse and removing the remaining non-resonant spins. Consecutive microwave pulses in a translated superlattice allow us to image these planes with a resolution better than 200 nm. We show that composite pulse techniques can reduce the sensitivity of the addressing to small variations in the relative position and intensity of the lattices. Furthermore, with this technique, we show that we are able to perform independent unitaries (single qubit quantum gates) on adjacent lattice sites with a single composite pulse. Finally, we perform randomized benchmarking, similar to that done by Olmschenk et al., to measure the error per randomized computational gate for these numerically generated composite pulses.

[2] This work is supported by a PFC grant from the National Science Foundation

11:54AM N2.00008 Preparation of two-particle total hyperfine spin-singlets via spin-changing interactions, SUNGKIT YIP, CHAO-CHUN HJUANG, Institute of Physics, Academia Sinica, MING-SHIEN CHANG, IAMOP, Academia Sinica — For (hyperfine-)spin-1 or spin-2 bosons in a one-dimensional optical lattice in the regime of one particle per site, we have shown [1] that there is a large (interaction) parameter regime where the system has dimerized ground states. Using a period-two superlattice, these dimerized states can be adiabatically transformed to a collection of singlet pairs, or vice versa. Here we describe, starting from two hyperfine spin-1 or 2 particles both with $m_F = 0$, how spin-changing dynamics under the influence of spin dependent interaction and quadratic Zeeman field can generate two-particle singlets, thus allow us to in principle create these exotic dimerized states. These spin-1 or 2 singlet pairs may also have quantum information science applications.

12:06PM N2.00009 Strongly interacting fermions in a 1D optical lattice\textsuperscript{1}. ARIEL SOMMER, LAWRENCE CHEUK, MARK KU, WASEEM BAKR, TARİK YEFSAH, MARTIN ZWIERLEIN, Department of Physics, MIT-Harvard Center for Ultracold Atoms, and Research Laboratory of Electronics, MIT, Cambridge, Massachusetts 02139, USA — Strongly correlated fermions in an array of two-dimensional planes coupled via tunneling serve as an important model system for high-temperature superconductors and layered organic conductors. We realize this model using ultracold fermionic Li atoms in a one-dimensional optical lattice near a Feshbach resonance. The depth of the lattice controls the interlayer coupling, and tunes the system between three and two dimensions. Pairing between fermions is studied using radio-frequency spectroscopy. The binding energy of fermion pairs is determined along the dimensional crossover and for different interaction strengths through the BEC-BCS crossover.

\textsuperscript{1}This work was supported by the NSF, AFOSR-MURI, ARO-MURI, ONR, DARPA YFA, a grant from the Army Research Office with funding from the DARPA OLE program, the David and Lucile Packard Foundation and the Alfred P. Sloan Foundation.

12:18PM N2.00010 Instabilities of Spin-polarized Fermions in Optical Lattice, CHEN YEN LAI, CHUNTAI SHI, SHAN-WEN TS AI, University of California Riverside — We study a two species fermion mixture with different populations on a square lattice, which can be modeled by a Hubbard Hamiltonian with on-site inter-species interaction. Such a model can be realized in a cold atom system with fermionic atoms in two different hyperfine states loaded on an optical lattice, and with interaction strength that can be tuned by an external magnetic field. When one of the fermion species is close to half-filling, the system is highly affected by lattice effects. We find several correlated phases for this system, including spin density wave state, d-wave charge density wave state, and p-wave superfluid state for the minority species. We study this system using a functional renormalization group method, determining its phase diagram and providing an estimate for the critical temperature of each phase. These phases emerge from a combination of interaction, population imbalance, and lattice effects. Lattice effects in particular lead to a much richer phase diagram than that of an imbalanced mixture of fermionic gas.

Thursday, June 7, 2012 10:30AM - 12:30PM - Session N3 Electron Interactions with Atoms and Molecules Grand Ballroom E - Chair: Don Madison, Missouri University of Science and Technology

10:30AM N3.00001 Radiative electron attachment to molecules of astrophysical interest. Benchmark study of CN\textsuperscript{-}.\textsuperscript{1} VIATCHESLAV KOKOULINE, Dep. of Physics, University of Central Florida, NICOLAS DOUGUET, Dep. of Chemical Engineering and Materials Science, Univ. of California at Davis, OLIVIER DULIEU, MAURICE RAOUTL, Laboratoire Aime Cotton, Université Paris XI, ANN E. OREL, Dep. of Chemical Engineering and Materials Science, Univ. of California at Davis — We develop a first-principles approach to study the process of radiative electron attachment (REA) to linear molecules of astrophysical interest $\text{Mol} + e^{-} \rightarrow \text{Mol}^{-} + h\nu$. ($\text{Mol}^- = \text{C}_n\text{H}^-, \text{C}_n\text{N}^-$). The approach is based on accurate ab initio calculations of electronic bound and continuum states of the negative ion. The electronic continuum states are obtained with the complex-Kohn variational method. A preliminary calculation for the formation of the simplest observed ion, CN$^-$, by REA gave a low rate coefficient. We will present also a preliminary result for the C$_4$H$^-$ formation by REA. For this molecule, the REA rate coefficient is expected to be somewhat larger due to the Renner-Teller non-adiabatic coupling that should enhance electron capture. The goal of this study is to answer the question if negative molecular ions C$_n$H$^-$ and C$_n$N$^-$ recently observed in the interstellar space could indeed be formed by REA as previously suggested.

\textsuperscript{1}This work is supported by the DOE Office of Basic Energy Science and the National Science Foundation, Grant No’s PHY-08-55092 and PHY-08-55622.

10:42AM N3.00002 Low-energy electron scattering from water vapor, KEVIN RALPHS, GABRIELA SERNA, LEIGH HARGREAVES, MURTADHA A. KHAKOO, California State University Fullerton, Physics Department, CA, 92834, CARL WINSTEAD, B. VINCENT MCKOY, Caltech Physical Chemistry, Pasadena, CA, 91125 — Absolute differential and integral cross section data for elastic scattering and electronic excitation of water molecules by low-energy electron impact are presented. Cross sections were obtained for the elastic and lowest lying 6 states, which dissociate to form the hydroxyl radical. The investigation is focused on OH due to its importance in living systems. The energy range of the measurements was between 1 – 100eV for the elastic data and 9 – 20eV for the excitation data. The absolute scale of the excitation data was established by comparison with the elastic scattering results of Khakoo et al. [1]. The present elastic data were compared to earlier data from our laboratory [1], to the data of [2] and others, to investigate a notable difference between the two sets of data. The excitation data are compared to earlier data from Thorn et al. [3] and further extend their data to near threshold energies. Important agreements and differences are observed between the two data sets and are discussed.


10:54AM N3.00003 Mechanisms of dissociative recombination of N$_2$H$^+$ and HCO$^{+1}$. SAMANTHA FONSECA DOS SANTOS, NICOLAS DOUGUET, ANN OREL, UCDavis, VIATCHESLAV KOKOULINE, UCF — N$_2$H$^+$ and HCO$^{+1}$ are among the first molecular ions observed in the interstellar medium. They are both formed by fast proton transfer mechanisms and are destroyed either by taking part on the molecular synthesis of more complex molecules or by dissociative recombination (DR). Given the astrophysical importance of these ions, their DR rates have been the subject of several different studies over the years. Recently, good agreement between theory and experiment have been achieved for HCO$^+$; however this is not the case for N$_2$H$^+$. This is mainly due to the fact that previous theories only considered the direct DR mechanism in their calculations. Applying a general simplified model based on multichannel quantum defect theory that accounts for all the main ingredients of indirect DR we calculate cross sections and DR rates for N$_2$H$^+$ as well as for HCO$^+$ using an improved coupling scheme.

\textsuperscript{1}This work was supported the DOE, Office of Basic Energy Science and the National Science Foundation, Grant No’s. PHY-08-55092 and PHY-08-55622
11:06AM N3.00004 Refutation of a propensity rule in low-energy electron scattering by neon atoms, LEIGH HARGREAVES, COLIN CAMPBELL, MURTADHA A. KHAKOO, California State University Fullerton, OLEG ZATSARINNY, KLAUS BARTSCHAT, Drake University — Since the work of Kohmoto and Fano [1] there has been considerable interest in the sign of the 'orientation' parameter \( L_{\perp} \), which describes the angular momentum of an excited electronic state perpendicular to the scattering plane imparted by the projectile electron. In a polarization-correlation experiment, \( L_{\perp} \) can be related to the measurable Stokes parameter \( P_3 \) (\( L_{\perp} = -P_3 \)), which describes the circular polarization of the photon emitted perpendicular to the scattering plane. Of particular interest is the empirical observation that, for \( S \) to \( P \) transitions, \( P_3 \) universally trends to negative values for small scattering angles, regardless of the target or incident energy. A number of studies (e.g., [1-3]) have therefore considered the generality of this 'propensity rule' and its theoretical basis. Here, a recent joint experimental and theoretical study of electronic excitation of the resonant transition in neon by 25eV electrons is presented. In both the theoretical and experimental data it is observed that \( P_3 \) is positive at small scattering angles, demonstrating a refutation of this propensity rule, in disagreement with the classical arguments of Kohomoto and Fano [1].


11:18AM N3.00005 Dynamics of Dissociative Electron Attachment to Methanol Probed By 3-Dimensional Momentum Imaging1, DAN SLAUGHTER, HIDEHITO ADANIYA, THORSTEN WEBER, ALI BELKACEM, Lawrence Berkeley National Laboratory — Dissociation of a stable molecule by low-energy electrons via a resonant transient negative ion species, in the dissociative electron attachment (DEA) process, plays an important role in phenomena such as atmospheric and interstellar chemistry and radiation damage in biological systems by low-energy secondary electrons. DEA is also a useful tool in materials processing and can be used to control chemical reactions through enhancement of specific dissociation pathways. We present new data on the dynamics of DEA to methanol, which we have measured using a 4pi negative ion momentum spectrometer. The data reveal that the dynamics of DEA to this fundamental polyatomic molecule can be understood in terms of a few similarities with equivalent processes involving the much better-understood water anion [Haxton et al. Phys. Rev. A 84, 030701 (2011)] suggesting the possibility of successfully extending our experimental approach to study DEA dynamics in more complex systems.

1work performed under the auspices of the US DOE by LBNL under Contract DE-AC02-05CH11231

11:30AM N3.00006 Theoretical and Experimental Fully Differential Cross sections for 54 eV electron-impact ionization of oriented H22, ADAM UPshaw, DON MADISON, Missouri S&T, JAMES COLGAN, Los Alamos National Lab, XUEGUANG REN, ARNE SENFTLEBEN, THOMAS PFLEUGER, ALEXANDER DORN, JOACHIN ULLRICH, Max-Planck-Institute for Nuclear Physics, Heidelberg, Germany — Experimental fully differential cross sections are measured for 54 eV electron impact ionization of oriented H2. One final state electron is measured in the scattering plane at an angle of 50 degrees from the incident beam direction and the other final state electron is measured in a plane perpendicular to the incident beam. Both electrons have an energy of 18 eV. The experimental results will be compared with TDCC (time dependent close coupling) results and M3DW (molecular 3-body distorted wave) results. The importance of different scattering mechanisms will be discussed.

2This Research was supported by the National Science Foundation through Grant No. PHY-1068237 and Teragrid resources provided by the Texas Advanced Computing Center (Grant No.TG-MCA07S029)


11:54AM N3.00008 Ultrafast Electron Pulse (e,2e) Processes, HUA-CHIEH SHAO, ANTHONY STARACE, University of Nebraska-Lincoln, U.S.A., LARS MADSEN, Aarhus University, Denmark — Techniques for producing ultrafast electron pulses have been proposed and prospects for using such pulses to image electronic dynamics in the H atom and the hydrogen molecular ion have been theoretically demonstrated. The (e,2e) process provides a means to directly image the momentum distribution of the target. We explore here the possibility of observing the time dependence of a coherent superposition of target orbitals by means of the (e,2e) process with ultrafast incident electron pulses. Using scattering theory for a longitudinally coherent beam, we find that the momentum distribution of a coherent state of the H atom can be retrieved.

1Supported in part by NSF Grant No. PHY-0901673.
dynamics. In the strong field regime, rescattering effects are expected to change rapidly with ellipticity. These plateau enhancements are present in Cs driven in the plateau of the photoelectron energy spectrum. These enhancements have been attributed to a combination of multiphoton excitation and rescattering. $\gamma$ near IR (NIR). The Keldysh parameter, $\gamma$, provides a useful metric for ionization dynamics. Utilizing the scaling of $\gamma$, experiments in Cs in the mid-IR (MIR) can be compared to noble gases with recent experimental data [3]. We find overall good agreement between the two sets of independently measured data, but serious discrepancies with the published experimental data. A detailed investigation of the dependence of the results on the fixed detection angle of the “scattered projectile”, i.e., the faster of the two outgoing electrons, suggests that obtaining reliable results, both experimentally and theoretically, is highly challenging in the regime where the largest discrepancies are present. Consequently, care should be taken before much weight is put on the remaining deviations between experiment and theory. Further independent tests seem highly desirable.

**References:**


1Work supported by the United States National Science Foundation under PHY-1068140 and PHY-0903818, and by the TeraGrid/XSEDE allocation TG-PHY090031.
11:18AM N4.00005 Precision measurement of carrier-envelope phase dependence of ATI spectra for the noble gases using phase-tagging¹, A.M. SAYLER, T. RATHJE, S. FASOLD, D. ADOLPH, W. MÜLLER, D. HOFF, G. PAULUS, Institut für Physik und Quantenelektronik and Helmholtz Institut Jena, Max-Wien-Platz 1, 07743 Jena, Germany — Presented are the carrier-envelope phase (CEP) and energy dependent few-cycle above-threshold ionization (ATI) spectra for Xenon, Argon, Krypton and atomic Hydrogen. This data was obtained by a phase tagging technique which is based on a novel robust, real-time, every-single-shot technique for determining the CEP via a stereographic ATI setup. The CEP is calculated and output in real-time and this information is then used to tag ATI spectra to investigate their dependence on the relative CEP. This technique along with calculations of the CEP dependence of atomic Hydrogen allow for the determination of the absolute CEP and energy dependent ATI spectra of all gases measured.

¹This work was supported by LaserLab Europe and a grant PA 730/4 from the German Research Foundation (DFG).

11:30AM N4.00006 Potential Barrier Features of Three-Photon Ionization Processes in Atoms³, LIANG-WEN PI, ANTHONY STARACE, University of Nebraska-Lincoln — We report here model potential results on the frequency dependence of three-photon generalized ionization cross sections from closed subshells of rare gas and other atoms. We find dramatic, resonance-like effects in three-photon ionization processes, which can be explained by potential barriers in the effective radial potential experienced by a photoexcited electron. In the case of Ar and Xe, our calculations show that such potential barriers may affect not only the final state of the electron, but also the intermediate-state electron wave packet at energies in the vicinity of the barrier. Such effects have been demonstrated numerically as a function of frequency in two-photon ionization processes [1]. Here we show that these effects are quite general by considering the multiphoton cross sections for ionization of Ar and Xe within a single-active-electron, central-potential model.


11:42AM N4.00007 Photoionization and Electron-Ion Recombination of Ar XVI and Ar XVII², SULTANA NAHAR, Ohio State U — Results on photoionization and electron-ion recombination of Ar XVII and Ar XVII obtained from unified method will be reported. The method, based on relativistic Breit-Pauli R-matrix method and close-coupling approximation, (i) subsumes both the radiative and dielectronic recombination and (ii) provides self-consistent sets of photoionization and recombination cross sections, σPI and σRC. Important features for level-specific σPI and recombination rate coefficients (αRI), such as for diagnostic w, x, y, z X-ray lines of Ar XVII in the ultraviolet region of astrophysical spectra will be illustrated. Monochromatic decay dominates the low energy photoionization and low temperature recombination rates. However, high energy resonances in σPI introduce a DR bump at high temperature recombination. While the 1s-2p core excitations enhance the background of αRI(nSLJ) at n=2 thresholds, the resonances become much weaker beyond them. The extensive sets of results correspond to fine structure levels with n ≤ 10 and 0 ≤ l ≤ 9. They include 98 levels of Ar XVI of total angular momenta 1/2 ≤ J ≤ 17/2 and 191 levels of Ar XVII of 0 ≤ J ≤ 9. The present αRI(T) with temperature show good agreement with ava

²This work is supported in part by DOE, Office of Science, Division of Chemical Sciences, Geosciences, and Biosciences, under Grant No. DE-FG03-96ER14646.

11:54AM N4.00008 Ionization of Excited Atoms in Intense, Low Frequency Single-Cycle Fields², SHA LI, ROBERT JONES, University of Virginia — We have employed intense THz pulses to explore strong-field, single-cycle ionization of low-lying Rydberg states in the low-frequency limit. In contrast to the ground-state atoms commonly used as targets for intense laser experiments, excited atoms and polar molecules can exhibit large linear Stark shifts in the presence of static or slowly varying fields. These shifts can have a significant effect on the ionization probability and dynamics in the field. In the experiments, sodium Rydberg atoms are laser-excited using two ns dye lasers and then exposed to a single-cycle, 10ps THz pulse produced via optical rectification in LiNbO3 of a tilted pulse front, 100fs, 780nm laser pulse. A time-of-flight spectrometer is used to record the ionization yield and energy distribution of the ejected electrons as a function of principal quantum number and the THz field strength. The measurements are compared with those of previous experiments on long-pulse microwave and ramped-field ionization of higher-lying Rydberg states and with the results of classical Monte Carlo simulations.

12:06PM N4.00009 Interatomic Coulombic Decay (ICD) in deep inner-shell vacancy cascades¹, D. RAY, R.W. DUNFORD, S.H. SOUTHWORTH, E.P. KANTER, B. KRAESSIG, L. YOUNG, D.A. ARMS, E.M. DUFRESNE, D.A. WALKO, X-Ray Science Division, Argonne National Laboratory, O. VENDRELL, S.-K. SON, R. SANTRA², Center for Free-Electron Laser Science, DESY, Germany — The photoionization of an inner-shell electron in a heavy atom triggers a vacancy cascade with the emission of x-ray fluorescence and Auger electrons leading to its final charge states. If the atom is part of a molecule or cluster, the decay process may involve removal of the valence electrons on the neighboring atoms thereby forming several charge centers and resulting in the Coulomb explosion of the system. This phenomenon in molecules where the valence electrons on the neighboring atoms play a significant role in the decay process is called Interatomic Coulombic Decay (ICD) [1]. The focus of this work is to explore the ICD effect in XeF₂ [2] following K-shell ionization of the Xe atom near 34.5 keV. We compare the total charge produced following Xe Ko or Kβ fluorescence decay from atomic Xe and from Xe in XeF₂ molecules. We present both experimental and calculational evidence that the fluorine atoms get involved in the decay process and the molecules start undergoing structural changes during the vacancy cascade.


¹Supported by U.S. Department of Energy (DOE) Office of Science, Division of Chemical, Geophysical and Biological Sciences.
²Department of Physics, University of Hamburg, Germany
10:30AM N5.00001 Quadratically-coupled optomechanical systems: spectrum and dynamics. M. BHATTACHARYA, H. SHI, Department of Physics, Rochester Institute of Technology, Rochester, NY 14623 — Optomechanical systems, which commonly involve a high finesse optical cavity coupled to the linear displacement of a mechanical oscillator, are currently of great interest for applications in quantum information, communication and measurement. Recently instead, a coupling quadratic in the mechanical displacement has been engineered in various systems. These include resonator setups with membranes, cold atoms and microdisks. Neglecting at first dissipation and noise, we present the exact eigenstates of the generic quadratic optomechanical Hamiltonian, examine the corresponding spectrum in the limit of strong coupling, quantify the bipartite entanglement in the system, and describe the unitary-evolution as well as measurement-based engineering of nonclassical states of the system. We show that several of our results are in qualitative contrast with those from the case of linear optomechanical coupling and address briefly the presence of dissipation and the case of quartic coupling recently realized using a tilted membrane in a cavity.

10:42AM N5.00002 Macroscopic tunneling of a membrane in an optomechanical double-well potential, LUKAS BUCHMANN, University of Arizona, LIN ZHANG, Shaanxi Normal University, ARAVIND CHIRUVELLI, University or Arizona, PIERRE MEYSTRE, University of Arizona — The quantum tunneling of a macroscopic mechanical object is considered in a “membrane-in-the-middle” optomechanical resonator. We show theoretically that a cavity mode which couples quadratically to the membrane’s position can create highly tunable adiabatic double-well potentials, which together with the high Q-factors demonstrated in such membranes render the observation of macroscopic quantum tunneling possible. We also show how a pulsed measurement scheme using a linearly coupled mode of the cavity can be used to monitor the tunneling.

1Supported by the DARPA ORCHID program.

10:54AM N5.00003 Suppression of extraneous thermal noise in cavity optomechanics, YI ZHAO, DALZIEL WILSON, K.-K. NI, H. J. KIMBLE, Norman Bridge Laboratory of Physics, 12-33, California Institute of Technology, Pasadena, California 91125. — Extraneous thermal motion can limit displacement sensitivity and radiation pressure effects, such as optical cooling, in a cavity-optomechanical system. Here we present an active noise suppression scheme and its experimental implementation. Our technique involves mapping a measurement of the extraneous noise onto the frequency of the incident laser field to stabilize the associated cavity-laser detuning. The main challenge is to selectively sense and suppress extraneous thermal noise without affecting motion of the oscillator. Our solution is to monitor two modes of the optical cavity, each with different sensitivity to the oscillator’s motion but similar sensitivity to the extraneous thermal motion. This information is used to imprint “anti-noise” onto the frequency of the incident laser field. In our system, based on a nano-mechanical membrane coupled to a Fabry-Pérot cavity, simulation and experiment demonstrate that extraneous thermal noise can be selectively suppressed without substantially affecting motion of the oscillator and that the associated limit on optical cooling can be reduced. Details of this work are presented in [1].


2Research supported by the DARPA ORCHID program, by the DoD NSSEFF program, by NSF Grant PHY-0652914, and by the Institute for Quantum Information and Matter.

11:06AM N5.00004 Characterization of the motional state of a quantum mechanical oscillator by coherent state transfer, HYOJUN SEOK, LUKAS BUCHMANN, SWATI SINGH, STEVEN STEINKE, PIERRE MEYSTRE, B2 Institute, Department of Physics and College of Optical Sciences, University of Arizona — We investigate theoretically a measurement scheme for the characterization of the motional state of a mechanical oscillator operating deep in the quantum regime. It is based on the coherent optomechanical transfer of the state of the mechanical element to the intracavity light field of an optical resonator with one end-mirror mounted on that oscillator. We consider both the case where the optical field is present at all times and the situation where it is turned on following the preparation of mechanical state. The roles of decoherence and dissipation on the fidelity of state transfer are considered in detail.

1NSF, the DARPA ORCHID and QuASAR programs and the US ARO

11:18AM N5.00005 Indirect position sensing and state control in a coupled BEC-mechanical system, STEVEN STEINKE, SWATI SINGH, PIERRE MEYSTRE, B2 Institute, College of Optical Sciences, and Department of Physics, University of Arizona, KEITH SCHWAB, Applied Physics, California Institute of Technology, MUKUND VENGALATTORE, Laboratory of Atomic and Solid State Physics, Cornell University — We investigate the dynamics of a moving mechanical micromembrane magnetically coupled to a spinor Bose-Einstein condensate. The Larmor precession frequency of spins in the condensate depends on the position of the membrane; thus, non-destructively imaging the spin state of the atoms reveals the position of the membrane. By considering the quantum back-action of the measurement procedure and including the effects of dissipation on the membrane, we obtain the ultimate sensitivity of such an indirect measurement protocol. In addition, we explore the possibility of using the entanglement between the membrane and the highly non-classical spin state of the BEC to produce exotic states of the membrane.

This work was supported by the DARPA ORCHID program through a grant from AFOSR.

11:30AM N5.00006 Anderson localization and anomalous Slow Absorption of Stationary Light by Disorder, RAZMIK UNANYAN, NIKOLAI LAUK, MICHAEL FLEISCHHAUER, Department of Physics and Research Center OPTIMAS, University of Kaiserslautern — We investigate the long time behavior of stationary light generated in an electromagnetically induced transparency (EIT) medium in the presence of randomly distributed absorbing impurities. By assuming a Poisson distribution for impurity atoms in the EIT medium we show that the absorption process can be much slower than naively expected. We show that this anomalous absorption of light is a consequence of the analogue of Anderson localization in the diffusion regime. A simple expression for the absorption for long times is derived in the case of perfect absorbing atoms. We show that it is described by \( \exp\left(-\alpha t^{1/3}\right) \), where \( \alpha \) is a constant depending on the concentration of impurities and thus is much slower than expected exponential decay.

11:42AM N5.00007 Co- and Counter- propagating fields in an four level ‘N-scheme’, FRANK A. NARDUCCI, JON P. DAVIS, Naval Air Systems Command — A four level “N-scheme” atomic system consists of a standard EIT configuration with an additional level being driven by an additional switch field. We theoretically extend our earlier studies of this model to include a counter-propagating, weak probe field. We investigate the dispersion experienced by the weak probe under a variety of conditions including cold and warm samples, as well as weak and strong switching fields. We find conditions in which the forward propagating probe field experiences normal dispersion while the backward propagating field experiences negative dispersion. We examine regions of high dispersion with vanishing absorption. We discuss applications of our results to high-dispersion gyroscopes.

3Supported by an In-house Applied Research (IAR) Grant
11:54AM N5.00008 Optical storage with electromagnetically induced transparency in cold atoms at a high optical depth\textsuperscript{1}. SHANCHAO ZHANG, SHUYU ZHOU, CHANG LIU, J.F. CHEN, Department of Physics, The Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong, China, JIANMING WEN, Department of Physics and National Laboratory of Solid State Microstructures, Nanjing University, Nanjing, Jiangsu, China, M.M.T. LOY, G.K.L. WONG, SHENGWANG DU, Department of Physics, The Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong, China — We report experimental demonstration of efficient optical storage with electromagnetically induced transparency (EIT) in a dense cold \textsuperscript{85}Rb atomic ensemble trapped in a two-dimensional magneto-optical trap. By varying the optical depth (OD) from 0 to 140, we observe that the optimal storage efficiency for coherent optical pulses has a saturation value of 50\% as OD > 50. Our result is consistent with that obtained from hot vapor cell experiments which suggest that a four-wave mixing nonlinear process degrades the EIT storage coherence and efficiency. We apply this EIT quantum memory for narrow-band single photons with controllable waveforms, and obtain an optimal storage efficiency of 49\%±3\% for single-photon wave packets. This is the highest single-photon storage efficiency reported up to today and brings the EIT atomic quantum memory close to practical application because an efficiency of above 50\% is necessary to operate the memory within non-cloning regime and beat the classical limit.

\textsuperscript{1}The work was supported by the Hong Kong Research Grants Council (Project No. 600710, DAG_S09/10.SC06, and DAG08/09.SC02)

12:06PM N5.00009 Improved Optical Magnetometer Based on Electromagnetically Induced Transparency in a Ring-Cavity Setup, BHASKAR ROY BARDHAN, MOOCHAN KIM, JONATHAN DOWLING, Louisiana State University — We propose and simulate a ring-gyro optical magnetometer based on polarization rotation of an optical field in an electromagnetically induced transparency (EIT) system. By properly choosing the polarization orientations of the optical field and the transition energy levels, the transparency conditions for the polarization components are derived for the EIT system inserted into the ring-cavity setup as a cell. As the optical field passes through the cell, the fluctuations of the Rabi frequency as well as the density inside the cell, due to the fluctuations in the laser field, give rise to the dephasing of the polarization vector. We show that using the setup it is possible to achieve very sensitive measurement of the magnetic field. Besides, by making several round trips of the photons, the dephasing effects can be removed by some suitable dynamical decoupling schemes implemented with additional waveplates in the setup. This enables us to obtain long interrogation length for the EIT based optical magnetometer.

Thursday, June 7, 2012 10:30AM - 12:30PM — Session N6 Quantum Networks and Hybrid Quantum Systems — Garden 4 - Chair: Luming Duan, University of Michigan - Ann Arbor

10:30AM N6.00001 An Elementary Quantum Network of Single Atoms in Optical Cavities, ANDREAS REISERER, STEPHAN RITTER, CHRISTIAN NOELLEKE, CAROLIN HAHN, ANDREAS NEUJNER, MANUEL UPHOFF, MARTIN MUECKE, EDEN FIGUEROA, JOERG BOCHMANN, GERHARD REMPE, Max-Planck-Institute of Quantum Optics, Garching, Germany — A quantum network consists of stationary nodes that are connected by quantum channels. Besides fundamental interest, such a quantum network is a prerequisite for distributed quantum computing architectures and has numerous applications in quantum communication. Here we present a prototype of such a quantum network based on two single atoms that are trapped in remote optical cavities and connected by an optical fiber link. The atom-cavity systems form universal quantum nodes in the sense that they are capable of sending, receiving, processing, storing and releasing quantum information that is encoded in the polarization of single photons. Via the temporal control of a coherent dark state we demonstrate the faithful transfer of a quantum state from one atom to the other. This is accomplished in the conceptually most fundamental way: by the coherent emission and absorption of a single photon. In the same way, we create a maximally entangled state between the two nodes that are in independent laboratories and separated by 20m. Due to its high efficiency and high fidelity (<0.9) our cavity-based approach paves the way towards large-scale quantum networks and their applications.

10:42AM N6.00002 Heralded entanglement of two remote atoms, MICHAEL KRUG, JULIAN HOFMANN, NORBERT ORTEGEL, LEA GERARD, KAI REDEKER, FLORIAN HENKEL, WENJAMIN ROSENFELD, MARKUS WEBER, HARALD WEINFURTER, LMU, Munich, MPQ, Garching — Entanglement between atomic quantum memories at remote locations will be a key resource for future applications in quantum communication. One possibility to generate such entanglement over large distances is entanglement swapping starting from two quantum memories each entangled with a photon. The photons can be transported to a Bell-state measurement where after the atomic quantum memories are projected onto an entangled state. We have set up two independently operated single atom experiments separated by 20 m. Via a spontaneous decay process each quantum memory, in our case a single Rb-87 atom, emits a single photon whose polarization is entangled with the atomic spin. The photons one emitted from each atom are collected into single-mode optical fibers guided to a non-polarizing 50-50 beam-splitter and detected by avalanche photodetectors. Bunching of indistinguishable photons allows to perform a Bell-state measurement on the photons. Conditioned on the registration of particular two-photon coincidences the spin states of both atoms are measured. The observed correlations clearly prove the entanglement of the two atoms. This is a first step towards creating a basic node of a quantum network as well as a key prerequisite for a future loophole-free test of Bell’s inequality.

10:54AM N6.00003 Spectral control of spin qubits in diamond photonic structures\textsuperscript{1}, VICTOR ACOSTA, CHARLES SANTORI, ANDREI FARAON, ZHIHONG HUANG, RAYMOND BEAUSOLEIL, Hewlett-Packard Laboratories, Palo Alto, CA — Integrated photonic networks based on cavity-coupled spin impurities offer a promising platform for scalable quantum computing. A key ingredient for this technology involves heralding entanglement by interfering indistinguishable photons emitted by pairs of identical spin qubits. The nitrogen-vacancy (NV) center in diamond is an attractive candidate for such a spin-photon interface, as it exhibits long-lived electronic spin coherence, rapid spin manipulation and readout, and the coexistence of both robust cycling and spin-altering Lambda-type transitions. We discuss current research in our lab to control the spectral properties of single NV centers by dynamic Stark tuning [1] and cavity Purcell enhancement [2]. In particular, we report progress on fabricating photonic structures in ultra-pure diamond, where NV centers are likely to have favorable optical properties.

\textsuperscript{1}This work was supported by the Defense Advanced Research Projects Agency (HR0011-09-1-0006) and The Regents of the University of California.

11:06AM N6.00004 Ultrafast Quantum Processing at Room-Temperature in Bulk Diamond Phonons, BENJAMIN SUSSMAN, PHILIP BUSTARD, National Research Council Canada, K.C. LEE, MICHAEL SPRAGUE, JOSHUA NUNN, NATHAN LANGFORD, X.-M. JIN, IAN WALMSLEY, University of Oxford, DOUG MOFFATT, RUNE LAUSTEN, National Research Council Canada — The two-level system comprised of the acoustic phonon and optical phonon of bulk diamond provides a unique opportunity for quantum processing at room-temperature with ultrafast rates. We present several applications including the generation of macroscopic non-classical states, a quantum memory for storing broad-band photons, and the generation of true random numbers from vacuum fluctuations.
information networks. A mesoscopic ensemble. These results hold promise for studies of dynamics and disorder in many-body systems with tunable interactions and for scalable quantum atomic Rb gas and are converted into light. As the principal quantum number n is increased beyond \( \sim 70 \), no more than a single excitation is retrieved from a macroscopic solid at room temperature. We enlist this mode to demonstrate entanglement between two macroscopic, spatially separated diamonds at room temperature with ultrashort pulses and a far-off-resonance Raman interaction. We measured the concurrence of the joint state of the Raman-scattered photons to determine that the optical phonon modes in the two diamonds were entangled. Our results demonstrate that entanglement can persist in the vibrational motion of macroscopic solids at room temperature. 

1Royal Society, Engineering and Physical Sciences Research Council (grant GR/S82176/01), EU IP Q-ESSENCE (grant 248095), EU ITN FASTQUAST, U.S. European Office of Aerospace Research and Development (grant 093020), Clarendon Fund.

2Author 1 and 2 equally contributed to the work.

3Second Affiliation: Centre for Quantum Technologies, National University of Singapore

4Second Affiliation: Centre for Quantum Technologies, National University of Singapore

11:30AM N6.00006 Spectroscopy of composite solid-state spin environments in diamond. NIR BAR-GILL, MY LINH PHAM, Harvard University, CHINMAY BELTHANGADY, DAVID LE SAGE, Harvard-Smithsonian Center for Astrophysics, MIKHAIL LUKIN, AMIR YACOBY, Harvard University, PAOLA CAPPELLARO, MIT, RONALD WALSWORTH, Harvard-Smithsonian Center for Astrophysics — We apply dynamical decoupling pulse sequences to nitrogen-vacancy centers in diamond in order to spectrally decompose the dynamics of their spin environment, which consists of nuclear and electronic spin impurities. We study a variety of diamond samples to identify the dynamics of the different spin baths and the interplay between them. These results are useful for the basic understanding of spin dynamics in solid-state systems and the central spin problem and could inform efforts in engineering optimized samples for collective quantum information processing and quantum metrology.

11:42AM N6.00007 Coupling ultra-cold atoms with nano-mechanics, ANDREW GERACI, University of Nevada, Reno, MATT EARDLEY, National Institute of Standards and Technology, Boulder, CO, CRIS MONTOYA, University of Nevada, Reno, JOHN KITCHING, National Institute of Standards and Technology, Boulder, CO. — Recently there has been a significant interplay between the fields of solid-state and atomic physics, ranging from using ultra-cold atoms to simulate condensed-matter systems to physically coupling cold atoms with solid state devices such as micro-resonators. In particular, micro-mechanical resonators can be used to manipulate and probe cold atomic samples with single-spin sensitivity and sub-micron spatial resolution. We describe ongoing experimental efforts to couple laser-cooled Rb atoms to a magnetic cantilever tip, and discuss prospects for using nano-resonators for individual lattice-site addressing of atoms trapped in optical lattices [1]. Looking forward, hybrid quantum systems consisting of cold atoms interfaced with mechanical devices may have applications in quantum information science.


11:54AM N6.00008 Quantum interface between an electrical circuit and a single atom. DAVID KIELPINSKI, Griffith University, D. KAFRI, Joint Quantum Institute/NIST, M.J. WOOLLEY, G.J. MILBURN, Centre for Engineered Quantum Systems, University of Queensland, J.M. TAYLOR, Joint Quantum Institute/NIST — We show how to bridge the divide between atomic systems and electronic devices by engineering a coupling between the motion of a single ion and the quantised electric field of a resonant circuit. The coupling uses parametric modulation of the circuit capacitance by a MEMS device to bridge the gap in timescales between the ion motion and circuit frequency. Our method can be used to couple the internal state of an ion to the quantised circuit with the same speed as the internal-state coupling between two ions. The parametric driving of the coupling adds negligible decoherence to the system. All the well-known quantum information protocols linking ion internal and motional states can be converted to protocols between circuit photons and ion internal states. Our results enable quantum interfaces between solid state qubits, atomic qubits, and light, and lay the groundwork for a direct quantum connection between electrical and atomic metrology standards.

12:06PM N6.00009 Atomic excitation with propagating light pulse and quantum memory with a half cavity.1 YIMIN WANG, JIRI MINAR, VALERIO SCARANI, Centre for Quantum Technologies, National University of Singapore, Singapore, GABRIEL HETET, Institute for Experimental Physics, University of Innsbruck, Austria — State mapping between atoms and photons and photon-phonon interactions play a key role in scalable quantum information processing. First, we consider the interaction of a single atom with a quantized light pulse propagating in free space. We show the dependence of the atomic excitation on (i) the quantum state of the pulse and (ii) the overlap between the pulse waveform and the atomic dipole pattern. We present a detailed study for both n-phonon Fock state and coherent state pulses with various temporal shapes. The work is extended to the dynamics of two spatial modes propagating from opposite directions to the atom. Second, we propose a setup for quantum memory based on a single two-level atom in a half cavity with a moving mirror. We show that various temporal shapes of incident photon can be efficiently stored and readout by shaping the time-dependent decay rate \( \gamma(t) \) describing the interaction between the atom and the light. We present an analytical expression for the efficiency of the storage and study its dependence on the ratio between the incident light field bandwidth and the atomic decay rate. We discuss possible implementations and experimental issues, particularly for a single atom or ion in a half cavity as well as a superconducting qubit in the circuit QED.

1We acknowledge the National Research Foundation, the Ministry of Education of Singapore and the Marie Curie Intra-European Action.

12:18PM N6.00010 Strongly interacting quantum excitations of a cold atomic gas. YAROGLAV DUDIN, ALEX KUZMICH, Georgia Institute of Technology, GEORGIA INSTITUTE OF TECHNOLOGY TEAM — Strong interactions of Rydberg atoms in a mesoscopic ensemble can be employed for fast preparation of desired many-particle states. In this work, Rydberg excitations are generated in an ultra-cold atomic Rb gas and are converted into light. As the principal quantum number \( n \) is increased beyond \( \sim 70 \), no more than a single excitation is retrieved from a mesoscopic ensemble. These results hold promise for studies of dynamics and disorder in many-body systems with tunable interactions and for scalable quantum information networks.

Thursday, June 7, 2012 10:30AM - 12:30PM – Session N7 Atomic and Molecular Structure and Spectroscopy | Terrace - Chair: Joseph Tan, NIST
10:30AM N7.00001 Spectroscopy of HfF$^+$ for the JILA electron electric dipole moment search. DANIEL GRESH, KEVIN COSSEL, TYLER COFFEY, LAURA SINCLAIR1, JUN YE, ERIC CORNELL, JILA, National Institute of Standards and Technology and University of Colorado Department of Physics. A low lying $^3\Delta_1$ state in HfF$^+$ and ThF$^+$ is an ideal candidate for a precise measurement of the electron electric dipole moment (eEDM). However, the electronic level structure of these species is not very well studied, and theoretical uncertainties are on the order of 1000 cm$^{-1}$ for many levels. We have used a recently developed novel technique, frequency comb velocity modulation spectroscopy (VMS), as well as cw-laser VMS for high-sensitivity, high-resolution, ion sensitive detection from 675-1000 nm (10000-14700 cm$^{-1}$). We report the measurement and assignment of 15 ro-vibrational bands in HfF$^+$ including accurate fits for the $^3\Delta_1$ metastable state and the $^1\Sigma^+$ ground state. In addition, we have characterized six excited states and discuss the implications for state preparation and readout in the eEDM experiment. This system will allow rapid characterization of ThF$^+$, which should further improve the sensitivity of the eEDM experiment. In addition to supporting the eEDM experiment, these studies provide data for testing and refining relativistic molecular structure calculations.

1Current affiliation: National Institute of Standards and Technology

10:42AM N7.00002 Calculation of ab initio potential curves for ground and low lying excited states of heteronuclear alkaline earth dimers BeCa$^+$, BeMg$^+$, and MgCa$^{++}$. SANDIPAN BANERJEE, JOHN MONTGOMERY, ROBIN CÔTE, Dept. of Physics, University of Connecticut. We report ab initio calculations on the ground and low lying excited states of $^3\Sigma^+$ and $^1\Pi$ symmetry for BeCa$^+$, BeMg$^+$, and MgCa$^{++}$. Valence multireference configuration interaction (MRCI) calculations were performed using complete active space self consistent field (CASSCF) orbitals. We use augmented correlation consistent valence quintuple zeta (aug-cc-pV5Z) basis set for our valence calculations. Core-valence and scalar relativistic effects are included at the CCSDT/cc-pCVTZK level of theory. Spectroscopic constants and bound vibrational levels are calculated, as well as Frank-Condon factors and electronic dipole transition moments between the dipole-allowed states. The static dipole and quadrupole polarizabilities, along with long range expansion coefficients are also reported.

1Supported by NSERC and by SHARCNET.

10:54AM N7.00003 Improved Energy Bounds and Basis Set Construction Strategies for Lithium1. GORDON DRAKE, University of Windsor, LIMING WANG, ZONG-CHAO YAN, University of New Brunswick. Improved nonrelativistic energy bounds for the low-lying states of lithium are presented using the variational method in Hylleraas coordinates. For example, the nonrelativistic energies for the infinite nuclear mass case are $-7.470/0.032/0.147/(1)$ a.u. for $1s^22s^22S$, $-7.354/0.088/0.144/0.171/(1)$ a.u. for $1s^22s^22S$, $-7.318/0.088/0.144/0.171/(1)$ a.u. for $1s^22s^22P$. We report the measurement and assignment of 15 ro-vibrational bands in HfF$^+$ including accurate fits for the $^3\Delta_1$ metastable state and the $^1\Sigma^+$ ground state. In addition, we have characterized six excited states and discuss the implications for state preparation and readout in the eEDM experiment. This system will allow rapid characterization of ThF$^+$, which should further improve the sensitivity of the eEDM experiment. In addition to supporting the eEDM experiment, these studies provide data for testing and refining relativistic molecular structure calculations.

1Supported by NSERC and by SHARCNET.

11:06AM N7.00004 Measurement of the first tune-out wavelength of K with an atom interferometer. WILLIAM HOLMGREN, RAISA TRUBKO, IVAN HROMADA, ALEX CRONIN, Department of Physics, University of Arizona. We present a measurement of the tune-out wavelength of K between the D1 and D2 lines with picometer uncertainty. Tune-out wavelengths occur where the dynamic polarizability of an atom equals zero between two transitions [1,2]. We find the tune-out wavelength by focusing a laser beam on one path of an atom and two plates are calculated. The atomic electric-dipole oscillator strength distribution is composed from combinations of theoretical and experimental data for energy levels, oscillator strengths, the polarizability, and photoionization cross sections.

1Supported in part by the NSF

11:18AM N7.00005 The observation of the dipole-dipole interaction by Ramsey method1. HYUNWOOK PARK, THOMAS GALLAGHER, University of Virginia. Previously, we reported a line broadening technique to quantitatively measure the dipole-dipole interaction in Rb Rydberg atoms [1]. As an alternative and more sensitive way, Ramsey interferometry is employed. Two identical microwave (MW) pulses, which are 200ns-long and separated by 300ns, are applied to Rb ns Rydberg atoms to drive $ns-np_{1/2}$ transitions ($n=33,36,39,$ and 41). As the MW frequency is swept through the resonance, Ramsey fringes with different contrast are observed depending on the atomic density. The dipole-dipole interaction washes out the fringe contrast at high atomic density, while isolated atoms produce 100% contrast Ramsey fringes. The interesting result is that the loss of the contrast as a function of the atomic density is not a linear process. The contrast drops rapidly with increasing density but it stops decreasing once it reaches at a certain non-zero contrast (Extremely high atomic density never completely destroys the contrast.). It turns out that the zero-shift dipole-dipole energy levels play a significant role in maintaining the contrast, even at very high atomic density. A simple model, based on the dipole-dipole interaction [1], reproduces the Ramsey lineshape including the surviving contrast at high density.

1Supported by The Air Force Office of Scientific Research.

11:30AM N7.00006 Long-range interactions between Mg atoms1. J.F. BABB, ITAMP, Harvard-Smithsonian. The long-range interactions between two and three Mg atoms, the interaction between a Mg atom and a perfectly conducting metallic plate, and between a Mg atom and two plates are calculated. The atomic electric-dipole oscillator strength distribution is composed from combinations of theoretical and experimental data for energy levels, oscillator strengths, the polarizability, and photoionization cross sections.

1Supported in part by the NSF
11:42AM N7.00007 Properties of Rn-like Th$^{4+}$ from microwave spectroscopy of high-L n=37 Rydberg states of Th$^{3+}$, CHRIS SMITH, JULIE KEELE, STEPHEN LUNDEEN, Colorado State University, CHARLES FEHRENBACK, Kansas State University — A recent microwave/RESIS study of n=37 Rydberg levels of Th$^{4+}$ led to the first measurements of dipole and quadrupole polarizabilities of Rn-like Th$^{4+}$ [1]. We report additional measurements that extend the data pattern to include the L=8 level and improve the precision of the L=14 and L = 15 levels. Together these new measurements allow improved determinations of both polarizabilities and a more precise test of theoretical calculations [2].


1Supported by the Chemical Sciences, Geosciences, and Biosciences Division of the Office of Basic Energy Sciences, Office of Science, U.S. Dept. of Energy

11:54AM N7.00008 Properties of Fr-like Th$^{3+}$ from microwave spectroscopy of high-L Rydberg states of Th$^{3+}$, JULIE KEELE, CHRIS SMITH, SHANNON WOODS, STEPHEN LUNDEEN, Colorado State University, CHARLES FEHRENBACK, Kansas State University — Spectroscopy of high-L n=28 Rydberg levels of Th$^{2+}$ was recently reported using the optical RESIS method [1]. Because the ground state of Fr-like Th$^{3+}$ is a $^2F_{5/2}$ level, each (n,L) Rydberg level of Th$^{2+}$ is split into six eigenstates whose relative positions are determined by long-range e-Th$^{3+}$ interactions. Measurements of those positions can be used to determine the Th$^{3+}$ properties that control those interactions, such as polarizabilities and permanent moments. We report a much improved study of n=28 levels with 9 ≤ L ≤ 12, obtained with the microwave/RESIS method. The higher precision measurements allow improved determinations of a wider range of Th$^{3+}$ properties and a better test of theoretical calculations [2].


1Supported by the Chemical Sciences, Geosciences, and Biosciences Division of the Office of Basic Energy Science, U.S. Department of Energy

12:06PM N7.00009 Relativistic many-body calculations of energies in a broad range of Lu-like ions from W$^{3+}$ to Fm$^{20+}$, U.I. SAFRONOVA, A.S. SAFRONOVA, University of Nevada, Reno — Energies of the [Xe]$4f^{14}5d^{3}$, [Xe]$4f^{14}5d^{2}6p$, and [Xe]$4f^{14}5d^{6}6p$ states of lutetiumlike ions with Z = 74-100 are determined using second-order relativistic many-body perturbation theory (RMBPT). Our calculations start from a Er-like Dirac-Fock potential ([Xe]$4f^{14}$ where [Xe] = 1s$^2$2s$^2$2p$^6$3s$^2$3p$^2$3d$^{10}$4s$^2$4p$^6$4d$^{10}$5s$^2$5p$^6$). Second-order Coulomb interactions are included. Correction for the frequency-dependence of the Breit interaction as well as Lamb shift correction to energies are taken into account in lowest order. The three-electron contributions to the energy are compared with the one- and two-electron contributions. They are found to contribute about 10-20% of the total second-order energy. The ratio of the third-order and second-order corrections to the one-electron contributions is found to be about 5-10%. A detailed discussion of the various contributions to the energy levels is given for Lu-like tungsten (Z = 74). Trends of excitation energies and Breit-Coulomb interactions are included. Measurements of those positions can be used to determine the Th$^{3+}$ properties that control those interactions, such as polarizabilities and permanent moments. We report a much improved study of n=28 levels with 9 ≤ L ≤ 12, obtained with the microwave/RESIS method. The higher precision measurements allow improved determinations of a wider range of Th$^{3+}$ properties and a better test of theoretical calculations [2].


1Supported by the Chemical Sciences, Geosciences, and Biosciences Division of the Office of Basic Energy Science, U.S. Department of Energy

12:18PM N7.00010 Relativistic many-body calculation of energies, oscillator strengths, transition rates, lifetimes, multipole polarizabilities, and hyperfine constants of Th IV ion, MARIANNA SAFRONOVA, University of Delaware, ULYANA SAFRONOVA, University of Nevada, Reno — Atomic properties of the 24 low-lying ns, npj, ndj, nfvj, and ngj states in Th IV ion are calculated using the high-precision relativistic all-order method where all single, double, and partial triple excitations of the Dirac-Fock wave functions are included to all orders of perturbation theory. Recommended values are provided for a large number of electric-dipole matrix elements, oscillator strengths, transition rates, and lifetimes. Scalar polarizabilities of the ground and six excited states (5fj, 6dj, 7pj, and 7s states) and tensor polarizabilities of the 5fj, 6dj, and 7pj/2 states are evaluated. The uncertainties of the recommended values are estimated. The hyperfine structure of the 229Th IV ion is investigated. The hyperfine A- and B-values are determined for the low-lying levels listed above. These calculations provide recommended values critically evaluated for their accuracy for a number of Th IV atomic properties for use in theoretical modeling as well as in planning and analysis of various experiments including RESIS studies of actinide ions and development of ultraprecise nuclear clock.

1This work was sponsored in part by the NSF.

Thursday, June 7, 2012 2:00PM - 3:36PM
Session P2 Synthetic Gauge Fields and Optical Lattices Grand Ballroom GF - Chair: Congjun Wu, University of California, San Diego

2:00PM P2.00001 Experimental Realization of Strong Effective Magnetic Fields in an Optical Lattice, YU-AO CHEN, Hefei National Laboratory for Physical Sciences at Microscale and Department of Modern Physics, University of Science and Technology of China, China, MONIKA AIDELBURGER, MARCOS ATALA, Faculty for Physics, Ludwig-Maximilans-University, Schellingstrasse 4, 80799 Munich, Germany, SYLVAIN NASCIMBENE, Laboratoire Kastler Brossel, CNRS, UPMC, Ecole Normale Superieure, 24 rue Lhomond, 75005 Paris, France, STEFAN TROTZKY, Department of Physics, CQIQC, and Institute for Optical Sciences, University of Toronto, MSSM1A7 Canada, IMMANUEL BLOCH, Max-Planck-Institute for Quantum Optics, Hans-Kopfermann-Strasse 1, 85748 Garching, Germany — Ultracold atoms in an optical lattice are promising candidates to study quantum many-body phenomena, such as the integer or fractional quantum Hall effect. Here we report about the experimental realization of strong effective magnetic fields with ultracold atoms using Raman assisted tunneling in an optical superlattice. We studied the nature of the frustrated ground state in the presence of an effective staggered magnetic field from its momentum distribution and directly revealed the quantum cyclotron orbit of a single atom exposed to the magnetic field.

1This work was supported by the DFG (FOR635, FOR801), the EU (STREP, NAMEQUAM, Marie Curie Fellowship to S. N.), and DARPA (OLE program).
We investigate the dynamics of a Bose-Einstein condensate (BEC) in the presence of spin-orbit coupling and a one-dimensional optical lattice. We show that the combination of the experimentally already realized spin-orbit coupling and the optical lattice potential yields a flat ground state Bloch energy band. The dynamical and Landau instabilities of the BEC in the spin-orbit coupled optical lattice are also investigated.

This work is supported by DARPA-YFA, ARO, NSF, and AFOSR.

2:24PM P2.00003 Phase-Sensitive Detection for Unconventional Bose-Einstein Condensations
ZI CAI, Daniel of Physics, University of California, San Diego, LUMING DUAN, Department of Physics, University of Michigan, CONGJUN WU, Department of Physics, University of California, San Diego — We propose a phase-sensitive detection scheme to identify the unconventional \( p_x \pm ip_y \) symmetry of the condensate wavefunctions of bosons, which have already been proposed and realized in high bands in optical lattices. Using the impulsive Raman operation combined with time-of-flight imaging, the off-diagonal correlation functions in momentum space give rise to the relative phase information between different components of condensate wavefunctions. This scheme is robust against the interaction and interband effects, and provides smoking gun evidence for unconventional Bose-Einstein condensations with nontrival condensation symmetries.

2:36PM P2.00004 Topological phase transition in an \( sp^\prime \) orbital chain, XIAOPENG LI, Department of Physics and Astronomy, University of Pittsburgh, ERHAI ZHAO, Department of Physics and Astronomy, George Mason University, W. VINCENT LIU, Department of Physics and Astronomy, University of Pittsburgh — We study an \( sp^\prime \) orbital chain. The existence of edge states is discovered for this system. The quantum phases of the chain filled with fermions are studied with exact diagonalization. We find a topological phase of fermions with edge states occupied. The topological phase is robust against small interactions. With sufficiently strong interaction the fermion system undergoes a topological phase transition to a superfluid state with a vortex supersolid or an exciton condensate, and the condensation symmetry is \( sp^\prime \). Physics Frontier Center. K.J.-G. thanks CONACYT; L.J.L. thanks NSERC and M.C.B. thanks the NIST-ARRA program.

3:00PM P2.00006 Gauge Field Induced Momentum Transport in an Optical Lattice, PATRICK WINDPASSINGER, JULIAN STRUCK, MALTE WEINBERG, CHRISTOPH OESCHLAEGER, JULIETTE SIMONET, KLAUS SENGSTOCK, Institute of Laser Physics, University of Hamburg, QUANTUM GASES TEAM — We present the experimental realization of a widely tuneable artificial gauge field for ultracold atoms in a one-dimensional optical lattice. We can simulate any Peierls phase ranging from zero to \( 2\pi \) in the tunneling matrix elements by applying an external periodic force to the atoms which is time irreversibly. This way it is possible to prepare ground state superfluids as well as out-of-equilibrium states at arbitrary finite quasi-momentum. Extending these ideas to two-dimensional non-rectangular optical lattices it is possible to realize staggered magnetic field configurations with very large fluxes per plaquette. These results present a new step towards the simulation of strong field physics in optical lattices which may result in the realization of exotic phases like quantum Hall states and other topological ordered phases with ultracold atoms.

3:12PM P2.00007 Bose Hubbard Model in a Synthetic Magnetic Field: Novel Chiral Mott Insulator State, ARUN PARAKEKANTI, University of Toronto, MAHESWAR MAJI, Indian Institute of Science, Bangalore, ARYA DHAR, Indian Institute of Astrophysics, Bangalore, TAPAN MISHRA, International Center for Theoretical Sciences, Bangalore, RAMESH PII, Goa University, SUBROTO MUKERJEE, Indian Institute of Science, Bangalore — Motivated by recent developments in realizing synthetic gauge fields for ultracold atoms, we study the Bose Hubbard model in the presence of a half magnetic flux quantum per lattice plaquette. We show, using density matrix renormalization group calculations and Monte Carlo simulations, that this “fully frustrated” Bose Hubbard model supports a novel Chiral Mott insulator phase with staggered loop currents for intermediate Hubbard repulsion on a two-leg ladder. This Chiral Mott insulator is flanked by a superfluid with staggered currents at weak repulsion, and an ordinary Mott insulator at strong repulsion. We discuss physical pictures for the Chiral Mott insulator as a vortex supersolid or an exciton condensate, and present a variational wavefunction which captures its essential correlations. We discuss observables, such as the gap, the momentum distribution, and loop current order across the phase diagram and propose interference measurements to detect the Chiral Mott state.

3:24PM P2.00008 Towards the observation of a Dicke type phase transition in spin-orbit coupled BECs, PETER ENGEELS, CHRIS HAMNER, JIAJIA CHANG, Washington State University — Spin-orbit coupling plays a major role in many condensed matter systems. Utilizing Raman coupling between two hyperfine states it is possible to add spin-orbit coupling to atomic systems as well. This is an important step for investigating condensed matter physics with ultracold atoms. Motivated by recent theoretical results we experimentally investigate a Dicke-model type phase transition in spin-orbit coupled \(^{87}\)Rb BECs. We report on recent and ongoing work.

We acknowledge support from NSF and ARO.

Thursday, June 7, 2012 2:00PM - 3:36PM –
Session P3 Experimental Probes of Atoms, Molecules, Clusters and Surfaces
Chair: Frank Narducci
2:00PM P3.00001 Electric dipole polarizabilities of atomic clusters of Sodium, ANTHONY LIANG, University of Southern California, JOHN BOWLAN, Fritz-Haber-Institut der Max-Planck-Gesellschaft, WALTER DEHEER, Georgia Institute of Technology, VITALY KRESIN COLLABORATION — A new discussion of the electronic shell structure of simple metal clusters is presented. Due to size quantization, cluster valence electrons order into energy shells as in atoms. We show that the oscillation of electric dipole polarizability as a function of size for sodium clusters (both in amplitude and shell closing numbers) can be explained by spherical well filling of electron wavefunctions. The shell closing numbers are closely examined. Interestingly, most theories involving cluster shape deformations do not yield the measured amplitude and closing numbers, while an existing simple spherical shape theory has correctly predicts both. This may hint at the occurrence of proposed resonant shape coexistence in nanoclusters. We also discuss the trend of oscillations (again, both in amplitude and shell closing numbers) in measurements of atomic separation energy of sodium clusters, the magnetic moments of nickel clusters, the magnetic moment of the sodium cluster Na69, and photoabsorption of sodium clusters, and point out interesting similarities. It appears that there may be more universal properties originating from shell filling in simple metal clusters than previously observed. The electric and magnetic field deflection measurements were carried out with a 20 K sodium cluster molecular beam apparatus.

2:12PM P3.00002 Double and triple ionization of silver clusters by electron impact, AVIK HALDER, ANTHONY LIANG, University of Southern California, CHUNRONG YIN, Argonne National Laboratory, VITALY KRESIN, University of Southern California — Metal clusters are finite droplets of delocalized electrons with discrete energy levels, due to the small confinement volume, often referred to as “artificial atoms” or “superatoms.” Ionization processes involving clusters provide insight into the energetics of charging of finite quantum systems. While the evolution of the single-ionization energy with cluster size has been extensively studied, less is known about multiple ionization thresholds and efficiencies. We probed the production of several selected silver cluster cations Ag40+ and Ag50+ by electron impact ionization. The scaling of ionization thresholds with particle radius follows the metallic droplet model, but, curiously, with a slope which is significantly different from the previous literature values for single ionization. Another observation is that as the electron energy increases, the yield of high-charge cations grows faster than that of singly-charged Ag4+. This behavior is consistent with the power-law dependence of post-threshold ionization known for atomic systems. Mechanisms involved in multiple ionization phenomena in metal clusters appear far from completely understood and call for further experimental and theoretical examination.

2:24PM P3.00003 Spectrally encoded optical/x-ray relative delay with ~10 fs RMS resolution, RYAN COFFEE, MINA BIONTA, CHRISTOPH BOSTEDT, MATTIAH CHELOUT, DAVID FRITZ, NICK HARTMANN, HENRIK LEMKE, MARC MESSER-SCHMIDT, DANIEL RATNER, SEBASTIAN SCHORB, LCLS-SLAC, JAMES CRYAN, JAMES GLOANNIA, MARIANO TRIGO, PULSE-Stanford, MARION HARMAND, SVEN TOLEIKIS, DESY, MARCO CAMMARATA, Univ. Rennes, DOUG FRENCH, Penn. State, DANIEL KANE, Mesa Photonics, LCLS-TIMING COLLABORATION — We present a spectral encoding technique that measures the single-shot relative delay between optical and x-ray laser pulses at the Linac Coherent Light Source. The technique has now been shown capable of resolving relative delays with an RMS accuracy down to 10 fs for both soft and hard x-rays. We sort the single-shot measurements into time-ordered traces and construct a scanning spectrogram representation of the x-ray/optical cross-correlation reminiscent of frequency resolved optical gating. We will discuss how such measurements can be used to reconstruct the ultrafast material response to the x-ray pulses. Once the material response is known, it may be possible to reverse the algorithm to reconstruct the average temporal shape of the x-ray pulses.

2:36PM P3.00004 Spectroscopy of the Cs 6s-5d quadrupole transition for qubit measurements, TIAN XIA, ALEX CARR, GANG LI, SIYUAN ZHANG, MARK SAFFMAN, University of Wisconsin — We have performed spectroscopy of the Cs 6s5/2 – 5d5/2 quadrupole transition using a heated thermal cell and a sample of cold trapped atoms. Measurements of the excited state hyperfine splittings have been used to determine values for the hyperfine constants. This transition is of interest for background free measurements on Cs qubits, as well as narrow line cooling since the Doppler temperature is only about 3 μK. We will report on experimental progress towards laser cooling and hyperfine qubit state detection using the quadrupole transition.

This research was carried out at the Linac Coherent Light Source (LCLS).

2:48PM P3.00005 Time-Dependent Electron Interactions in Double-Rydberg Wavepackets, F. ROBICHEAUX, Auburn University, X. ZHANG, R.R. JONES, University of Virginia — We consider the evolution of double-Rydberg wavepackets in which the two valence electrons in Ba are radially localized via sequential short-pulse laser excitation. Following the launch of the wavepackets, the atoms are exposed to a subpicosecond, half-cycle electric field pulse (HCP). The atoms either directly ionize during the HCP or are further excited by it, autoionizing to a distribution of Ba+ Rydberg states. These ions are then subjected to a field ramp which ionizes the most highly excited Ba+ to Ba2+. The Ba2+ signal is recorded as a function of the relative launch times of the two electrons and as a function of the HCP delay. The data show a dramatic reduction in the Ba2+ yield when the HCP arrives after the excitation of the second wavepacket, suggesting that autoionization occurs almost instantly. This conclusion is supported by both full quantum and classical Monte Carlo calculations. The quantum calculations numerically solve the time dependent Schrödinger equation using a radial grid of points for each electron and coupled spherical harmonics. These calculations do not include the HCP but clearly show that more than 80% of the atoms ionize over one Rydberg period and the character of the ionization depends on the relative launch times.

3:00PM P3.00006 Manipulation of Raman Resonances Using Magnetic Fields, SARA A. DESAVAGE, Aerospace Mass Properties Analysis, Inc., JON P. DAVIS, FRANK A. NARDUCCI, Naval Air Systems Command — We have theoretically and experimentally studied Raman resonances in multi-level atoms (specifically 85Rb). Our emphasis has been on varying the relative orientation of the magnetic field with respect to the propagation direction of the Raman fields. We find that, in general, the spectrum consists of up to 11 peaks. By considering selection rules, we show that it is possible to orient the magnetic field so that either a 6 peak spectrum or 5 peak spectrum results, depending on whether the Raman fields contain a polarization component along the magnetic field direction or not. Furthermore, we find that the spectrum is not always symmetric with respect to the magnetically insensitive transition (clock transition). We explore the origins of the asymmetry and the overall shape of the spectra. We will discuss applications to magnetically sensitive atom interferometry.

This work was supported by IARPA through ARO, and DARPA.

3:36PM P3.00008 Manipulation of Raman Resonances Using Magnetic Fields, SARA A. DESAVAGE, Aerospace Mass Properties Analysis, Inc., JON P. DAVIS, FRANK A. NARDUCCI, Naval Air Systems Command — We have theoretically and experimentally studied Raman resonances in multi-level atoms (specifically 85Rb). Our emphasis has been on varying the relative orientation of the magnetic field with respect to the propagation direction of the Raman fields. We find that, in general, the spectrum consists of up to 11 peaks. By considering selection rules, we show that it is possible to orient the magnetic field so that either a 6 peak spectrum or 5 peak spectrum results, depending on whether the Raman fields contain a polarization component along the magnetic field direction or not. Furthermore, we find that the spectrum is not always symmetric with respect to the magnetically insensitive transition (clock transition). We explore the origins of the asymmetry and the overall shape of the spectra. We will discuss applications to magnetically sensitive atom interferometry.

3:00PM P3.00006 Manipulation of Raman Resonances Using Magnetic Fields, SARA A. DESAVAGE, Aerospace Mass Properties Analysis, Inc., JON P. DAVIS, FRANK A. NARDUCCI, Naval Air Systems Command — We have theoretically and experimentally studied Raman resonances in multi-level atoms (specifically 85Rb). Our emphasis has been on varying the relative orientation of the magnetic field with respect to the propagation direction of the Raman fields. We find that, in general, the spectrum consists of up to 11 peaks. By considering selection rules, we show that it is possible to orient the magnetic field so that either a 6 peak spectrum or 5 peak spectrum results, depending on whether the Raman fields contain a polarization component along the magnetic field direction or not. Furthermore, we find that the spectrum is not always symmetric with respect to the magnetically insensitive transition (clock transition). We explore the origins of the asymmetry and the overall shape of the spectra. We will discuss applications to magnetically sensitive atom interferometry.

3Supported by ONR and a Section 219 grant.
To observe it, one must increase the time above the surface by decelerating the ions. We have for the first time decelerated O$_{2}^{+}$ ions to energies as low as 1 eV/q, below the minimum energy gained by the ions due to the acceleration by their image charge. As expected, no ion backscattering (trampoline effect) above dielectric (Ge) was observed and at the lowest ion kinetic energies, most of the observed x-rays were found to be emitted by the ions after surface contact.

1 Funding from the Natural Sciences and Engineering Council of Canada (Discovery and Strategic Network Grant programs) is gratefully acknowledged.

Thursday, June 7, 2012 2:00PM - 4:00PM –
Session P4 Non-equilibrium Dynamics in Ultracold Systems

2:00PM P4.00001 Acoustic analog of the dynamical Casimir effect in Bose-Einstein Condensates, JEAN-CRISTOPHE JASKULA, GUTHRIE PARTRIDGE, MARIE BONNEAU, JOSSELIN RUAUDEL, DENIS BOIRON, CHRISTOPHER WEST-BROOK, Institut d’Optique — Although we often picture the quantum vacuum as containing virtual quanta whose observable effects are only indirect, it is a remarkable prediction of quantum field theory that the vacuum can generate real particles when boundary conditions are suddenly changed. Thus the “dynamical Casimir effect” or the ‘Hawking radiation’ result in the spontaneous generation of photon pairs in an empty cavity whose boundaries are rapidly moving or at the horizon of a black hole. In 1981, W. Unruh pointed out an acoustic analog to Hawking radiation. Further work on this idea has developed into an entire field, and recently a stimulated analog to Hawking radiation has been observed using surface waves on water. Bose Einstein condensates are attractive candidates in which to study such analog models because their low temperatures promise to reveal quantum effects. We present the realization of an acoustic analog to the dynamical Casimir effect by modulating the confinement of a Bose-Einstein condensate. We show that correlated pairs of Bogoliubov quanta, both phonon-like and particle-like, are excited by this modulation, in a process that formally resembles parametric down conversion.

2:12PM P4.00002 Integrability versus Thermalizability in Isolated Quantum Systems, CHITRA RANGAN, SO-MAYEH M.A. MIRZAEI, University of Windsor, ON, Canada — We demonstrate the enhanced purification of the quantum state of a two-level system subject to a near-resonant driving field when in proximity to a gold nanoparticle. The quantum dynamics of the driven two-level system in the presence of decay is modelled by the Lindblad Master equation. The electrodynamics of the gold nanoparticle illuminated by the driving field and the field radiated by the atomic dipole is solved using a finite-difference time-domain method. We discover that the presence of a proximate gold nanoparticle enhances the purity of a driven two-level system even at short times.

2:24PM P4.00003 Relaxation Dynamics and Pre-thermalization in an Isolated Quantum System, MAXIM OLSHANII, University of Massachusetts Boston — The purpose of this presentation is to propose a rigorous measure of the degree of quantum thermalizability, consistent with the expected empirical manifestations of it. As a practical application of this measure, we devise a unified recipe for choosing an optimal set of conserved quantities to govern the after-relaxation values of observables, in both integrable quantum systems and in quantum systems in between integrable and thermalizable.

2:36PM P4.00004 Non-equilibrium dynamics of a 1D Bose gas in a flat optical lattice potential, AARON REINHARD, LAURA ZUNDEL, JEAN-FELIX RIOU, The Pennsylvania State University, JUAN CARRASQUILLA, MARCOS RIGOL, Georgetown University, DAVID WEISS, The Pennsylvania State University — We study the dynamics of a bundle of expanding 1D Bose gases in a nearly flat 1D optical lattice potential in the intermediate coupling regime, which presents a challenge to theory. We observe the time-evolving spatial and quasimomentum distributions at a range of 1D atom densities and 1D lattice depths. Since it is difficult to exactly model these non-equilibrium dynamics, we take a first step towards theoretical understanding by comparing our measurements to the results of a Gutzwiller mean-field model.

2:48PM P4.00005 Quantum flutter of supersonic particles in one-dimensional quantum liquids, CHARLES MATHY, Institute for Theoretical Atomic, Molecular and Optical Physics, MIKHAIL ZVONAREV, EUGENE DEMLER, Physics Department, Harvard University — We study the dynamics of an impurity injected at a supersonic velocity into a 1D gas of hardcore bosons, or faster than the Fermi velocity, in a fully polarized Fermi gas. We find that at long times the momentum of the impurity does not decay to zero, and demonstrate that the system exhibits a new type of coherent oscillation in which the impurity vibrates with respect to its correlation hole.

1 C.M. acknowledges support from the NSF through ITAMP at Harvard University and the Smithsonian Astrophysical Observatory.
3:00PM P4.00006 Asymptotic limit of momentum distribution functions in the sudden expansion of a spin-imbalanced Fermi gas in one dimension . STEPHAN LANGER, LMU Munich, CARLOS BOLECH, University of Cincinnati, IAN MCCULLOCH, University of Queensland, Brisbane, FABIAN HEIDRICH-MEISNER, LMU Munich, GUILIANO ORSO, University Paris Diderot, MARCOS RIGOL, Georgetown University — We study the sudden expansion of a spin-imbalanced Fermi gas in an optical lattice after quenching the trapping potential to zero, described by the attractive Hubbard model. Using time-dependent density matrix renormalization group simulations we demonstrate that the momentum distribution functions (MDFs) of majority and minority fermions become stationary after sufficiently long simulation times. Our main result is that the asymptotic form of the MDFs is fully determined by the integrals of motion of this integrable quantum system, namely the rapidities from the Bethe ansatz solution, which we show by a direct comparison of DMRG and Bethe ansatz predictions. We discuss the relevance of our results for the observation of Fulde-Ferrell-Larkin-Ovchinnikov correlations in one-dimensional systems, related to recent experiments from Rice University (Liao et al. Nature 467, 567 (2010)).

3:12PM P4.00007 Quantum Quench of a p-Wave Fermi Gas across the Quantum Phase Transition . SUKJIN YOON, GENTARO WATANABE, APCTP(Asia Pacific Center for Theoretical Physics), Korea — We investigate the non-equilibrium dynamics following a quantum quench across the quantum phase transition in a p-wave superfluid Fermi gas at zero temperature. This case is distinct from the s-wave case where the change from the BCS to BEC regime is just a crossover. The quench dynamics of a polar state as well as an axial state of the p-wave superfluid Fermi gas are studied. The time evolutions of the order parameter are obtained within a mean field approach and compared with the s-wave case.

3:24PM P4.00008 A new theoretical method to describe nonequilibrium cold atoms in optical lattices . KARLIS MIKELSONS, JIM FREERICKS, Georgetown University, H.R. KRISHNAMURTHY, Indian Institute of Science, Bangalore — We use perturbation theory in the hopping (strong-coupling expansion) to describe the nonequilibrium dynamics of strongly correlated fermions. Our expansion is a self-consistent expansion for the self-energy which goes beyond the RPA and allows for damping and relaxation effects. We apply this method to solve the homogeneous Fermi-Hubbard model driven by an external field. We investigate the damping of Bloch oscillations (for a uniform dc field) and show results for the current, the nonequilibrium density of states and the momentum distribution. We carefully benchmark the technique using the exact sum rules to determine its accuracy and we discuss regions of parameter space where the method no longer converges. This technique is quite competitive with other methods (such as DMFT) in the regions where it converges.

3:36PM P4.00009 No indirect increase in precision of energy measurements from nonlinearity in a two-well trap . HAN CHEN, JUHA JAVANAINEN, U. of Connecticut — We study a two-well trap containing a Bose-Einstein condensate as a prototype for interferometric measurements of the energy difference of the atoms between the two sides of the trap. The measurement relies on a coupling to atom numbers, which implies the Heisenberg limit of precision. However, it is known that a nonlinear scheme, a measurement coupling proportional to a power of atom number higher than one, may defeat the Heisenberg limit. Here we ask if the nonlinear atom-atom interaction that couples to the dynamics of the system as a whole could indirectly increase the precision of energy measurements. Our numerical analysis indicates that it is not the case.

3:48PM P4.00010 Pattern formation of quantum jumps with Rydberg atoms . TONY LEE, MICHAEL CROSS, California Institute of Technology — We study the nonequilibrium dynamics of quantum jumps in a one-dimensional chain of atoms. Each atom is driven on a strong transition to a short-lived state and on a weak transition to a metastable state. We choose the metastable state to be a Rydberg state so that when an atom jumps to the Rydberg state, it inhibits or enhances jumps in the neighboring atoms. This leads to rich spatiotemporal dynamics that are visible in the fluorescence of the strong transition. It also allows one to dissipatively prepare Rydberg crystals.

Thursday, June 7, 2012 2:00PM - 4:00PM –
Session P5 Quantum Memory and Nonlinear Optics Garden 3 - Chair: Jonathan Weinstein, University of Nevada

2:00PM P5.00001 Storage of Multiple Images using a Gradient Echo Memory in a Vapor Cell . ALBERTO MARINO, QUENTIN GLORIEUX, JEREMY CLARK, PAUL LÉTTE, Joint Quantum Institute, National Institute of Standards and Technology and the University of Maryland, Gaithersburg, MD 20899 USA — The development of a quantum memory (QM) that can store quantum states of light without a significant degradation is an active field of research, as QMs play a fundamental role in quantum information science. A number of different techniques have been developed for their implementation. In particular, the gradient echo memory (GEM) offers a promising technique with high recovery efficiencies and the ability of temporal multiplexing. We show that it is possible to use GEM for the simultaneous storage of multiple images, thus extending the multiplexing properties of this technique to the spatial domain. In order to implement the QM we use a 7 cm-long $^{85}\text{Rb}$ vapor cell with Ne buffer gas at a pressure of 5 Torr and a linearly varying magnetic field of 15 $\mu$T/cm along the cell. We use this configuration for the storage of two different images with a temporal delay between them and show that it is possible to temporally distinguish them after the retrieval process. We have obtained recovery efficiencies up to 8 % and storage times over 4 $\mu$s while still retaining a good spatial fidelity between the input and retrieved images. Finally, we study the effect of atomic diffusion on the storage of images and find that it limits the spatial resolution of the retrieved images.

2:12PM P5.00002 Characterization of a high efficiency optical memory for the storage of quantum light states . CONNOR KUPCHAK, RYAN THOMAS, ALEX LVOVSKY, Institute for Quantum Information Science, University of Calgary, INSTITUTE FOR QUANTUM INFORMATION SCIENCE, UNIVERSITY OF CALGARY TEAM — We have developed a coherent optical storage device based on a Gradient Echo Memory scheme showing efficiencies of above 65%. The memory is realized in a warm vapor of $^{85}\text{Rb}$ atoms utilizing a $\Lambda$-type energy level scheme. We use a co-propagating, co-rotating circular polarized pump beam coupled with pulsed coherent states to create an off-resonant Raman absorption line suitable for storage. Through sufficient filtration of the strong pump field, the stored light pulse is retrieved after a desired time and subjected to time-domain homodyne tomography. By repeating this sequence on an ensemble of 50 000 identical coherent states we gain enough information to completely reconstruct the quantum state of light retrieved from the memory. Furthermore, by repeating this characterization for a set of coherent states with at sufficient range of amplitudes we can completely characterize the memory process itself. This is possible by implementing a method devised by our group called coherent state Quantum Process Tomography which also has the capability to predict how well the memory will perform on any arbitrary quantum input state. We show our current storage efficiencies and what needs to be further done to demonstrate a true high efficiency, quantum optical memory.
explore the strong coupling regime for an atom in free space and investigate the scattering of Fock states from a two-level atom. We then generalize this to N-photon states with arbitrary spectral distribution functions and control, University of New Mexico — Traveling nonclassical states of light are important resources for quantum metrology, secure communication, and quantum computing.

BEN Q. BARAGIOLA, ROBERT L. COOK, Center for Quantum Information and Control, University of New Mexico, AGATA M. BRANCZYK, Department of Physics, University of Nevada, Reno — We have performed degenerate four-wave mixing experiments with cryogenically-cooled atomic ytterbium. We use buffer-gas cooling to prepare high optical density samples at a temperature of 5 K, cold enough to resolve the different isotopes and hyperfine transitions. We observe four-wave mixing. With cross-polarized pump and probe beams, we observe a conjugate beam only when the laser is closely detuned from the $^1S_0(F = 1/2) \rightarrow ^1P_1(F = 1/2)$ transition of the $^{171}$Yb ($I = 1/2$) isotope. Progress towards the generation of squeezed light will be discussed.

1This material is based upon work supported by National Science Foundation under Grant No. PHYS-0903847

2:36PM P5.00004 Multi-Spatial-Mode Noiseless Optical Amplifier
NEIL CORZO-TREJO, ALBERTO MARINO, PAUL LETT, Joint Quantum Institute / NIST-UMD — One of the most commonly-used optical linear amplifiers, the phase-insensitive amplifier (PIA), always degrades the signal-to-noise ratio of the amplified signal, and the degradation depends on the amount of gain. This problem can be avoided by the proper use of a phase-sensitive amplifier (PSA). An ideal PSA, under certain conditions, can amplify signals without degrading the signal-to-noise ratio of the input. In this sense, the PSA behaves as a noiseless amplifier. In particular, if the PSA can support multiple spatial modes it can perform noiseless amplification of images which is an important goal in imaging research. We implement a phase-sensitive optical amplifier using a four-wave mixing (4WM) process in rubidium vapor. We observe performance near the quantum limit for this type of amplifier over a range of experimental parameters. We compare the results to the ones expected for a PIA and find that our PSA behaves better than the PIA, as expected. Additionally, we observe that the amplifier supports multiple spatial modes (images) without a significant degradation of the input signal-to-noise ratio. To confirm the multi-spatial-mode character we study the behavior of the 4WM-based PSA for different spatial patterns and different spatial frequencies.

2This work was supported by DARPA and AFOSR.

2:48PM P5.00005 Quantum assisted enhancement of optical magnetometer with squeezed vacuum in hot Rb vapor
EUGENIY MIKHAILOV, TRAVIS HORROM, The College of William & Mary, ROBINJEET SINGH, Louisiana State University — We demonstrate enhancement to the sensitivity of an optical magnetometer based on the nonlinear magneto-optical Faraday effect in $^{87}$Rb vapor with the use of squeezed vacuum. We generate quantum squeezed vacuum states via the polarization self-rotation effect in hot $^{87}$Rb vapor exhibiting noise spectrum suppression ranging from frequencies of a few hundred Hz to several MHz. Injection of such squeezed states into a magneto-optical magnetometer provides broad band noise suppression of close to 2 dB. We study various parameters of the magnetometer such as Rb cell temperature, pump power, and the noise spectrum of the probe signal to identify the most favorable conditions for quantum enhanced magnetometry. Our experimental arrangement offers potential quantum improvement to the most sensitive magnetometers at frequencies down to hundreds of Hz, which can be useful for biological, geophysical, medical, or military sensing applications.

3:00PM P5.00006 Few-Photon Cross-Phase Modulation in Rb-Filled Photonic Bandgap Fibers
VIVEK VENKATARAMAN, KASTURI SAHA, ALEXANDER GAETA, Cornell University — We produce cross-phase shifts (XPS) of a few milliradians on a meter optical signal with <20 signal photons, using a two-photon transition in Rb vapor confined to photonic bandgap fibers. A weak 780-nm signal beam tuned close to the $5S_{1/2} \rightarrow 5P_{3/2}$ transition of Rb-85 is used to impart a nonlinear phase shift on a strong, counter-propagating 776-nm meter beam which is tuned close to the $5P_{3/2} \rightarrow 5D_{5/2}$ transition. Using the selection rules of the relevant transitions involved, we measure the XPS as a slight polarization rotation of the meter beam. A XPS of $\sim$0.3 milliradian per signal photon is induced in our system, which, to our knowledge, represents the largest such nonlinear phase shift induced in a single-pass through a room-temperature nonlinear medium. The system response time is shown to be <5 ns, primarily determined by the transit-time of the atoms across the fiber core. Such a system offers the potential to explore novel quantum nonlinear effects at ultralow powers.

3:12PM P5.00007 Superresolution at the quantum limit with coherent light and a homodyne-based parity detection scheme
KAUSHIK SESHADEESAN, Louisiana State University, PETR ANISIMOVA, Stony Brook University, HWANG LEE, JONATHAN DOWLING, Louisiana State University — We study a simple interferometric scheme that uses coherent light and a quantum inspired detection strategy based on the measurement of the parity of photon number in one of the output modes. The scheme provides sub-Rayleigh resolution while still operating at the shot noise limit in terms of the detected photon power. Although the parity observable can be implemented using photon number resolving detectors, accurate and efficient photon number resolution at large photon numbers becomes difficult. Alternatively, we show that the super-resolving parity signal can be inferred from a simple homodyne based measurement of the quadratures of the output coherent light, also at the shot noise limit. Due to its inherent simplicity and effectiveness, the scheme can potentially be improved to use existing technologies in satellite imaging and remote sensing such as in quantum laser radar (LADAR), where atmospheric absorption forbids the use of nonclassical states of light for any quantum enhancement and renders coherent light interferometry as the optimal choice.

3:24PM P5.00008 Coherent Rayleigh-Brillouin Scattering in High Intensity Laser Fields
BARRY CORNELLA, SERGEY GIMELSTEIN, ERC Inc., TAYLOR LILLY, University of Colorado Colorado Springs, ANDREW KETSDEVER, Air Force Research Laboratory — We have performed coherent Rayleigh-Brillouin scattering (CRBS) experiments on collisional gasses subject to laser intensities beyond those considered perturbative to the gasses’ thermodynamic parameters. CRBS is a four wave mixing scheme traditionally used for gas diagnostic applications when utilizing low intensity laser pulses. In these experiments high intensity laser pulses are used which yield signal lineshapes inconsistent with perturbative theory. Gas heating, weak ionization, and three dimensional effects are discussed as possible nonlinear optical effects which would have to be accounted for in order to model the high intensity regime. The cause of this altered lineshape may furthermore be used to diagnose the full effect of the laser pulses on the gas.

3:36PM P5.00009 N-Photon Wavepackets Interacting with an Arbitrary Quantum System
BEN Q. BARAGIOLA, ROBERT L. COOK, Center for Quantum Information and Control, University of New Mexico, AGATA M. BRANCZYK, Department of Physics and Centre for Quantum Information and Quantum Control, University of Toronto, JOSHUA COMBES, Center for Quantum Information and Control, University of New Mexico — Traveling nonclassical states of light are important resources for quantum metrology, secure communication, and quantum networks. Motivated by this, we derive master equations for an arbitrary quantum system (e.g. a quantum harmonic oscillator or a multi-level atom) interacting with a wavepacket of light prepared in an N-photon Fock state. We then generalize this to N-photon states with arbitrary spectral distribution functions and wavepackets in two polarization (or spatial) modes. Our method also allows the calculation of output field quantities. As an illustration of our formalism, we explore the strong coupling regime for an atom in free space and investigate the scattering of Fock states from a two-level atom.

1BQB acknowledges support from NSF PHYS-0969997
3:48PM P5.00010 Single atom lensing, ERIK STREEDE, ANDREAS JECHOW, BENJAMIN NORTON, SYLVI HAENDEL, VALDIS BLUMS, DAVID KIELPINSKI, Griffith University — The lens is a fundamental optical device for redirecting the path of light. We have observed the first lensing of light by a single atom. A $^{174}$Yb$^+$ ion is confined in a 3D RF Paul trap, laser cooled near the Doppler limit on the $\lambda=369.5$ nm transition, and imaged at wavelength scale resolution with a large aperture phase Fresnel lens (NA=0.64). Changes to the wavefront of the illumination light are measured from background-subtracted images at different image defocusings and laser detunings. The wavefront was observed to converge for negative laser detunings (positive focal lengths), diverge for positive detunings (negative focal lengths), and agrees with an analytic microscope model of a dipole radiator. The effective focal length of the atom is on the order of lambda near resonance.

Thursday, June 7, 2012 2:00PM - 3:48PM – Session P6 Entanglement and Error Correction Garden 4 - Chair: Nicholas Guise, NIST

2:00PM P6.00001 Quantum Entanglement in Spinor Bose-Einstein Condensates and the Preparation of Dicke State, ZHEN ZHANG, LUMING DUAN, University of Michigan-Ann Arbor — The spin-1 Bose Condensate system can exhibit many interesting phenomena under the effect of linear and quadratic Zeeman effects, resulting from the rich spin texture and the long range correlation in the system. The manybody ground state is shown and phase transition and entanglement properties are described. We also propose a method to prepare the Dicke state, with time evolution from a state relatively easy to realise from current experimental cooling methods. The entanglement depth, which based only on the measuring of collective spin operators, is used to characterise the entanglement in the final prepared state. Various noises in the preparation process are also discussed.

2:12PM P6.00002 Correcting detection error in quantum computation and state engineering through data processing1, CHAO SHEN, LUMING DUAN, University of Michigan-Ann Arbor — Quantum error correction in general is experimentally challenging as it requires significant expansion of the size of quantum circuits and accurate performance of quantum gates to fulfill the error threshold requirement. Here we propose a method much simpler for experimental implementation to correct arbitrary detection errors. The method is based on processing of data from repetitive experiments and can correct detection error of any magnitude, as long as the error magnitude is calibrated. The method is illustrated with its application to detection of multi-partite entanglement from quantum state engineering.

2:24PM P6.00003 Experimental demonstration of quantum gain in a zero-sum game, CHONG ZU, YUEXUAN WANG, XIUYING CHANG, Center for Quantum Information, IIFS, Tsinghua University, Beijing, China, ZHAOHUI WEI, Centre for Quantum Technologies, National University of Singapore, Singapore, SHENGYU ZHANG, Department of Computer Sci. and En., The Chinese University of Hong Kong, Hong Kong, LUMING DUAN, Department of Physics and MCTP, University of Michigan, Ann Arbor, Michigan, USA — We propose and experimentally demonstrate a zero-sum game which is in a fair Nash equilibrium for classical players, but a quantum player can always win using an appropriate strategy. The gain of the quantum player is measured experimentally under different quantum strategies and input states. It is found that the quantum gain is maximized under a maximally entangled state, but does not reduce to zero when entanglement disappears. Instead, it links with another kind of quantum correlation described by discord for the qubit case.

2:36PM P6.00004 Experimental demonstration of topological error correction1, XING-CAN YAO, WEI-BO GAO, YOU-JIN DENG, YU-AO CHEN, Hefei National Laboratory for Physical Sciences at Microscale and Department of Modern Physics, University of Science and Technology of China, China, JIAN-WEI PAN, Hefei National Laboratory for Physical Sciences at Microscale and Department of Modern Physics, University of Science and Technology of China, China, AUSTIN FOWLER, CQC2T, School of Physics, University of Melbourne, VIC 3010, Australia, ROBERT RAUSSENDORF, Department of Physics and Astronomy, University of British Columbia, Vancouver, BC, V6T 1Z1, Canada — Scalable quantum computing can only be achieved if qubits are manipulated fault-tolerantly. Topological error correction—a novel method which combines topological quantum computing and quantum error correction—possesses the highest known tolerable error rate for a local architecture. This scheme makes use of cluster states with topological properties and requires only nearest-neighbor interactions. Here we report the first experimental demonstration of topological error correction with an eight-photon cluster state. It is shown that a correlation can be protected against a single error on any qubit, and when all qubits are simultaneously subjected to errors with equal probability, the effective error rate can be significantly reduced. This demonstrates the viability of topological error correction. Our work represents the first experimental effort to achieve fault-tolerant quantum information processing by exploring the topological properties of quantum states.

2:48PM P6.00005 Accessible non-linear witnesses, NORBERT LÜTKENHAUS, OLEG GITTsovICH, JUAN MIGUEL ARRAZOLA, Institute for Quantum Computing, Department of Physics and Astronomy, University of Waterloo — Verification of entanglement is an important tool to characterize sources and devices for use in quantum computing and communication applications. Evaluation of entanglement witnesses are an especially valuable tool, especially for higher-dimensional systems, as they do not require a full reconstruction of the underlying quantum state (tomography). Linear witnesses can be extended to series of non-linear witnesses [1, 2] so that each element of this family detects a strictly larger set of entangled states than the previous one. In our contribution we show that one can construct series of accessible non-linear witnesses that can be evaluated using exactly the same data as for the evaluation of the original linear witness. This allows a reanalysis of published experimental data to strengthen statements about entanglement verification without the requirement to perform additional measurements. Accessible non-linear witnesses allow the verification of entanglement without critical dependence on having found the “right” linear witness. They can also enhance the statistical significance of the entanglement verification.

1This work has been supported by the NBRPC(973 Program) 2011CBA00300 (2011CBA00302), the IRAP MUSIQ program, the DARPA OLE program, the ARO and the AFOSR MURI program.

3:00PM P6.00006 Improved data analysis for verifying quantum nonlocality and entanglement, YANBAO ZHANG, University of Colorado at Boulder and National Institute of Standards and Technology, SCOTT GLANCY, EMANUEL KNILL, National Institute of Standards and Technology — Given a finite number of experimental results originating from local measurements on two separated quantum systems in an unknown state, are these systems nonlocally correlated or entangled with each other? These properties can be verified by violating a Bell inequality or satisfying an entanglement witness. However, violation or satisfaction could be due to statistical fluctuations in finite measurements. Rigorous upper bounds, on the maximum probability (i.e., the p-value) according to local realistic or separable states of a violation or satisfaction as high as the observed, are required. Here, we propose a rigorous upper bound that improves the known bound from large deviation theory [R. Gill, arXiv:quant-ph/0110137]. The proposed bound is robust against experimental instability and the memory loophole [J. Barrett et al., Phys. Rev. A 66, 042111 (2002)]. Compared with our previous method [Phys. Rev. A 84, 062118 (2011)], the proposed method takes advantage of the particular Bell inequality or entanglement witness tested in an experiment, so the computation complexity is reduced. Also, this method can be easily extended to test a set of independent Bell inequalities or entanglement witnesses simultaneously.
3:12PM P6.00007 Evaluation of joint probabilities for non-commuting observables from correlations between quantum clones. HOLGER HOFMANN, Hiroshima University — Universal quantum cloning processes must be able to copy all physical properties of a quantum system with equal fidelity. If the statistical interpretation of the quantum state is correct, quantum fluctuations of the input state are also copied, mapping the correlations between non-commuting observables onto the experimentally accessible correlations between separate systems. Here, I show that it is indeed possible to evaluate the correlations between the non-commuting properties of a quantum system from the correlations between measurements of two optimal quantum clones of the system. Significantly, the joint probabilities obtained from the analysis of cloning correlations are identical with the joint probabilities observed in weak measurements, indicating that such joint probabilities may provide the foundations for a consistent statistical interpretation of quantum physics.

3:24PM P6.00008 Quantum Polar Coding for Noisy Optical Quantum Channels1 , LASZLO GY-ONGYOSI, SANDOR IMRE, Budapest University of Technology and Economics — Polar channel coding is a revolutionary encoding and decoding scheme, which makes possible the construction of codewords to achieve the symmetric capacity of noisy communication channels. Here, we show that by using quantum polar codes, the symmetric classical capacity of optical channels can be achieved. We also demonstrate the existence of quantum polar codes capable of transmitting classical information privately, although initially these channels had zero private classical capacity. As we prove, there also exist polar coding-based codewords for the transmission of quantum entanglement; however, these channels are so noisy that they cannot transmit any quantum information.

The results discussed above are supported by the grant TAMOP-4.2.2.B-10/1-2010-0009 and COST Action MP1006.

3:36PM P6.00009 An ab-initio model of anomalous heating in planar ion traps . ARGHAVAN SAFAVI-NAINI, Harvard/ITAMP — Anomalous heating of trapped ions imposes a limit on the scalability of the planar trap architecture for quantum computation. Measurements of the electric field noise present in ion traps have determined the frequency scaling of this noise and its scaling with the distance from the ion to the trap surface [1,2]. These measurements suggest that a thermally activated random process is at work. We present a model that accounts for the noise due to oscillating dipoles on the trap electrode surface [3]. The dipoles are formed when atoms are adsorbed on the trap surface. We present calculations for the spectral noise density and its distance and frequency scaling. We go beyond independent dipoles and consider the effect of correlation between dipoles, presence of a monolayer on the trap surface and multi-photon processes on the spectral density.


Thursday, June 7, 2012 2:00PM - 4:00PM —
Session P7 Light-Matter Interactions and Structure —
Terrace - Chair: David Hall, Amherst College

2:00PM P7.00001 Absolute measurement of the nonlinear phase shift in the components of air at high intensity. JARED WAHLSTRAND, YU-HSIANG CHENG, YU-HSIN CHEN, HOWARD MILCHBERG, University of Maryland — Filamentary propagation of ultrashort optical pulses in gases is generally agreed to arise from an interplay between self-focusing due to the optical Kerr effect and defocusing from electrons freed by ionization of atoms and molecules. However, despite intensive investigation for many years, the optical nonlinearity is still not understood with much quantitative accuracy. We present the results of supercontinuum spectral interferometry measurements on the components of air using a thin gas target. These experiments provide absolute measurements of the instantaneous and delayed rotational response, as well as a time-dependent phase shift due to ionization. We find no sign of a higher-order Kerr effect up to intensities near the ionization threshold. These measurements promise to bring a new level of precision to nonlinear optics at high intensity.

2:12PM P7.00002 Post-Ionization Medium Response to a Femtosecond Laser Pulse1 , DMITRI A. ROMANOV, Department of Physics and Center for Advanced Photonics Research, Temple University, ROBERT J. LEVIS, Department of Chemistry and Center for Advanced Photonics Research, Temple University — When an intense, femtosecond laser pulse ionizes an atmosphere-pressure gas, the optical response of the medium differs drastically from that of a regular weakly-ionized plasma. The initial charge distribution resulting from ionization is microscopically inhomogeneous, with the average electron density of 10^{13}-10^{15} cm^{-3}. We considered the oscillations of virtually isolated and expanding electron clouds forced by the laser electric field. A simple analytical model predicts the amplitude of these forced oscillations as a function of time. This amplitude, as well as the related polarization of the medium, undergoes considerable enhancement when the system evolves through the transient resonance with the laser carrier frequency. The results impact the currently accepted picture of laser filamentation dynamics and call for modifications in existing theoretical models.

1 We gratefully acknowledge financial support through the AFOSR MURI grant FA9550-1-0-0561.

2:24PM P7.00003 Excitation of a single atom with a temporally shaped light pulses. GLEB MASLENIKOV, SYED ALJUNID, DAO HOANG LAN, KADIR DURAK, VICTOR LEONG, CHRISTIAN KURTSIEFER, Centre for Quantum Technologies / National Univ. Singapore — We investigate the interaction between a single atom and coherent optical pulses with a controlled temporal envelope. By switching the temporal shape from rising exponential to square profile, we show that the rising exponential envelope leads to higher excitation probability using lower photon number in a pulse. The atomic transition saturates for \( \approx 100 \) photons in a pulse. Rabi oscillations with 100 MHz frequency are visible in detected fluorescence for excitations powers of \( \approx 1300 \) photons in a 15 ns pulse. A possibility to excite the atom with pulses in a Fock states is discussed and the theoretical treatment is presented.

2 M. Stobinska et al., EPL 86 14007 (2009)

2:36PM P7.00004 Single-atom and multi-atom Excitation to Rydberg states. RUI HAN, Centre for Quantum Technologies, Singapore, HUI KHOON NG, Centre for Quantum Technologies, Singapore and DSO. National Laboratories, applied physics lab, Singapore, B.G. ENGELRT, Centre for Quantum Technologies, National University of Singapore, Singapore — We study two-photon Raman transitions between states \( |0\rangle \) and \( |1\rangle \) via an intermediate state \( |e\rangle \) that is far detuned so that it does not get significantly populated. This problem is often solved by adiabatic elimination in an interaction picture in which one then has an effective two-level Hamiltonian for states \( |1\rangle \) and \( |0\rangle \). However, there is more than one interaction picture and results may depend on which one is chosen (see E. Brion et al. J. Phys. A: Math. Theor. 40 1033 (2007), for example). In this talk, we present a full treatment of the single-atom Raman transition without adiabatic elimination. This serves as a benchmark for the choice of the correct interaction picture to use for adiabatic elimination for other situations. One of the very useful examples is the collective Rydberg excitation in a multi-atom system, where we discuss the correction in adjusting the detuning to compensate for the light shift compare to a single-atom system.

We gratefully acknowledge financial support through the AFOSR MURI grant FA9550 10-1-0561.
2:48PM P7.00005 Modeling A@C_{60} atoms: diffuse versus square-well confining pseudopotentials1, JONATHON KING, JOSHUA OXLEY, VALERIY DOLMATOV, University of North Alabama — An empirical model approximating the C_{60} cage potential by a square-well confining potential has played an important role in providing the initial understanding of photoionization spectra of A@C_{60} endohedral atoms [1]. However, the square-well potential is discontinuous at its boarders. A more realistic confining potential must be diffuse, obviously. However, it is not at all clear apriori to what degree replacement of a square-well potential by a diffuse potential may alter predictability of the model. In particular, should a large array of predicted data and phenomena made on the basis of a square-well potential model be re-studied with an eye on a more realistic diffuse potential boarders of C_{60}? It will be shown in this presentation, with H@C_{60} and Xe@C_{60} as case studies, that both the square-well and diffuse confining potentials lead to practically identical calculated data for A@C_{60} photoionization spectra. Moreover, the latter are largely insensitive to the degree of diffuseness of the potential, in reasonable limits. Hence, either of said potentials is equally suitable for mimicking the C_{60} cage.


3:00PM P7.00006 Creating and transporting Trojan wave packets1, S. YE, B. WYKER, X. ZHANG, F.B. DUNNING, Rice University, S. YOSHIDA, Vienna University of Technology, C.O. REINHOLD, Oak Ridge National Laboratory, J. BURGDORFER, Vienna University of Technology — The non-dispersive localized atomic states that have been most widely studied theoretically are termed Trojan wave packets because the mechanism responsible for suppressing dispersion (which is of classical origin) parallels that for stabilization of Jupiter's Trojan asteroids located near the Lagrange points. In the present work non-dispersive localized Trojan wave packets with n ∼ 305 moving in near-circular orbits are created in the laboratory, and transported to localized near-circular Trojan states of higher n, n ∼ 600, by driving with a linearly-polarized sinusoidal electric field whose period is slowly increased. The protocol is remarkably efficient with over 80% of the initial atoms being transferred to the higher n states. The mechanisms involved in localization and transport are discussed with the aid of classical trajectory Monte Carlo simulations.

1Research supported by the NSF, the Robert A. Welch Foundation, and the FWF (Austria).

3:12PM P7.00007 Trojan wavepackets bound on Lagrange equilibrium points of two positive ions binary system in the strong magnetic field, MATTHEW KALINSKI, Utah State University — We once have shown that the combination of the Circularly Polarized Electromagnetic (CP) wave field and the central Coulomb proton field is capable to keep the hydrogen atom in the complex space-correlated coherent state of the electron in the rotating frame eliminating the principal time dependence [1]. This state corresponds to the stable and nondispersing electron wave packet moving around the circle in the laboratory frame. Here we show the existence of stable nondispersing single and two-electron wavepackets localized around Lagrange equilibrium points of two positive ions in binary star configuration executing cyclotron motion around each other in strong external magnetic field. Unlike for the normal Trojan wavepackets they do not require external CP field to localize and correspond exactly to atom size scaled Trojan asteroids in the Sun-Jupiter system. The exact numerical simulations using Split Operator Fast Fourier Transform method are also provided for the single electron while the approximate time-dependent Hartree simulations for two electrons.


3:24PM P7.00008 Attosecond Lighthouse Effect: from tilted waves to isolated harmonic beams, JONATHON WHEELER, ANTONIN BOROT, Laboratoire d’Optique Appliquée, HENRI VINCENTI, SYLVAIN MONCHOSE, CEA Saclay, AURELIEN RICCI, AURELIE JULIEN, ARNAUD MALVACHE, Laboratoire d’Optique Appliquée, FABIEN QUERE, CEA Saclay, RODRIGO LOPEZ-MARTENS, Laboratoire d’Optique Appliquée, PCO GROUP TEAM1, GROUPE PHYSIQUE À HAUTE INTENSITE TEAM2 — Spatio-temporal coupling (STC) within a laser pulse is normally a negative feature to be avoided as it leads to non-uniform pulse characteristics and reduced intensity at focus. In this study, STC is purposely introduced into the laser pulse leading to wavefront rotation at the focus. When such a modified focus is applied to plasma mirror harmonic generation, each harmonic pulse produced from cycle to cycle has a shifted propagation direction. Dependant on the degree of wavefront rotation introduced, this can lead from tilted harmonic spectra due to small displacements of the overlapping beams to fully isolated, individual pulses arising from each cycle of the driving laser pulse, the so-called Attosecond Lighthouse effect. This work discusses the recently measured results of spatially-separated, single harmonic beams from a solid target source obtained with 1kHz, CEP-locked, 800nm laser pulses of both 25 and 5 fs duration.

1Laboratoire d’Optique Appliquée, Ecole Nationale Supérieur de Techniques Avancées-ParisTech, Ecole Polytechnique, CNRS, 91761 Palaiseau Cedex, France
2Service des Photons, Atomes et Molécules, Commissariat à l’Energie Atomique, DSM/IRAMIS, CEN Saclay, 91191 GIF sur Yvette, France

3:36PM P7.00009 Coherent Perfect Rotation: The conservative analogue of CPA, MICHAEL CRESCI-MANNO, NATHAN DAWSON, JAMES ANDREWS, Dept. Physics and Astro, Youngstown State Univ. — The two classes of conservative, linear, optical rotary effects (optical activity and Faraday rotation) are distinguished by their behavior under time reversal. In analogy with coherent perfect absorption (CPA) resonances, where counter-propagating light fields are completely converted into other degrees of freedom, we show that in a linear conservative medium only time-odd (Faraday) rotation is capable of coherent perfect rotation, by which we mean the complete transfer of any arbitrarily oriented polarization of light into the other orthogonal polarization via the application of phased counter-propagating light fields. This contributes to the understanding of the importance of time reversal symmetry in perfect mode conversion that may be of use in optical device design.

3:48PM P7.00010 Discrete Energy Spectrum of a Classical Harmonic Oscillator in Classical Electromagnetic Zero-Point Radiation1, WAYNE HUANG, HERMAN BATELAAN, University of Nebraska-Lincoln — Since the early development of Quantum Mechanics, the discrete energy spectrum of atoms have been considered as the defining feature of Quantum Mechanics. However, when classical electromagnetic zero-point radiation is introduced as a modification of Classical Mechanics, our simulation shows that a classical harmonic oscillator can also exhibit a discrete energy absorption spectrum when excited by a laser pulse. This finding may be surprising given the use of a full classical theory, and it may help us identify fully quantum mechanical features in physical systems such as harmonic oscillator and ultimately atoms.

4:00PM - 4:00PM —
Session Q1 Poster Session III (4:00 pm - 6:00 pm) — Royal Ballroom

Q1.00001 ATOMIC AND MOLECULAR STRUCTURE AND PROPERTIES III —

1This work is supported by NSF Grant No. 0969386.
Q1.00002 Energies, radiative rates and Auger branching ratios of core-excited resonances for B-like isoelectronic sequence\(^1\), BINGCONG GOU, YAN SUN, CUICUI SANG, School of Physics, Beijing Institute of Technology, Beijing 100081, China — The relativistic energies, fine-structures, radiative rates, and Auger branching ratios of the core-excited 1s\(2p\) states for B-like isoelectronic sequences are studied using the saddle-point variation method and saddle-point complex-rotation method. Large-scale wavefunctions are used to obtain reliable results. Relativistic corrections and mass polarization effects are taken into account with first-order perturbation theory. The radiative rates of these states are reported and compared with available theoretical and experimental results. The radiative and Auger transition rates regularly change along the Boron isoelectronic sequence has been investigated. The Auger branching ratios of these resonances are discussed using spin-alignment-dependent theory. Calculated Auger channel energies and branching ratios are used to identify high resolution Auger spectrum in the collision experiments. Several unidentified experimental Auger lines are assigned. It is found that Auger decay of the five-electron core-excited states give significant contributions to the experimental Auger spectrum.

\(^1\)This work was supported by National Natural Science Foundation of China under Grant No. 11074022 and No.11164022.

Q1.00003 Hyperfine Structure in the \(^{87}\text{Rb}_2\) \(1_g\) State Below \(5^2S + 5^2P_1/2\) — T. BERGEMAN, SUNY Stony Brook, E. TIESINGA, P.S. JULIENNE, NIST, C.-C. TSAI, National ChengKung U., Taiwan, D. HEINZEN, U. Texas, Austin — Hyperfine structure in the \(\text{Rb}_2\) \(1_gP_{1/2}\) state was observed in photoassociation from cold atoms some time ago, but only partially analyzed. Our Hamiltonian includes the vibrational energy, \(G(v)\), rotational energy, \(B(v)\), hyperfine interaction, \(A(v)\), \(I\), and off-diagonal elements \(F_2\cdot I_{\text{imp}}\). \(F\) ranges from 1 to 6, \(I\) from \(-I\) to \(I\), where \(I=3\). The data scans were precisely calibrated by simultaneously etalon scans. For the 22 vibrational levels (over a range of 50) for which there is precise data, \(A(v)\) varies from 2.97×10\(^{-2}\) cm\(^{-1}\) to 3.15×10\(^{-2}\) cm\(^{-1}\). The \(G(v)\) and \(B(v)\) values allow us to construct a potential down to 32 cm\(^{-1}\) below the dissociation limit.

Q1.00004 Molecular Ion Spectroscopy\(^1\), KUANG CHEN, STEVEN SCHOWALTER, WADE RELLERGERT, SCOTT SULLIVAN, ERIC HUDSON, UCLA — We discuss our efforts to perform high-resolution spectroscopy of the BaCl\(^+\) ion, an exciting candidate for ultracold molecular ion studies. This work details our search for a predicted predissociation channel between the first-excited \(B^1\Sigma\) and \(A^1\Pi\) states. It is expected that the rovibrational resolution afforded by predissociation spectroscopy will allow us to efficiently measure molecular-ion rovibrational temperatures. This is a crucial step in confirming our method to produce ultracold molecular ions via sympathetic collisions with a \(40\text{Ca}\) MOT. To observe the predissociation of trapped BaCl\(^+\), we detect slight increases in fragment Ba\(^+\) with a novel time-of-flight device using radial extraction from a linear quadrupole trap.

\(^1\)Work supported by NSF grant No. PHY-1005453, ARO No. W911NF-10-1-0505, and AFOSR grant.

Q1.00005 Photoexcitation of high-\(n\), \(n \sim 300\), Rydberg states in the presence of an rf driving field near the final Kepler frequency\(^1\), S. YE, X. ZHANG, F.B. DUNNING, Rice University, S. YOSHIDA, J. BURGDÖRFER, Vienna University of Technology — The photoexcitation of very-high-\(n\), \(n \sim 300\), potassium Rydberg atoms in the presence of an rf driving field at, or near, the Kepler frequency of the final state is examined and allows the realization of quantum-optical protocols in truly mesoscopic atoms. When directly exciting \(4s\) \(\rightarrow np\) transitions using a uv laser, application of the drive field leads to the appearance of new features in the excitation spectrum that lie approximately midway between the \(np\) states. Whereas the size of these features increases with increasing drive field amplitude their positions remain largely unchanged. As the rf frequency is detuned from resonance, the features split, the separation of the components being equal to twice the detuning. The new features are attributed to multiphoton transitions to final \(ns\) and \(nd\) states that involve the absorption or emission of rf photons. Measurements further suggest that while the electron motion in the product states is locked to the drive field this results from post-excitation interactions with the field rather than the excitation process per se.

The results are analyzed using Floquet theory.

\(^1\)Research supported by the NSF, the Robert A. Welch Foundation, and the FWF (Austria).

Q1.00006 Transition Probabilities for Neutral Cerium from Boltzmann Analysis of Fourier Transform Spectra\(^1\), D.E. NITZ, St. Olaf College, J.J. CURRY, National Institute of Standards and Technology, M.J. BUUCK, N.P. MITCHELL, A.D. DEMANN, W.E. SHULL, St. Olaf College — The recent availability of a large set of absolute transition probabilities for neutral cerium (Lawler et al., J. Phys. B 43, 85701 (2010)) makes it possible to investigate the relative populations of the upper levels of these lines in radio metrically-calibrated spectra. In cases where these populations can be characterized by a single effective Boltzmann temperature, applying this temperature enables one to determine absolute transition probabilities for observable decay branches of nearby levels. While not as accurate as measurements based on branching fractions and lifetimes, the method can be applied to levels whose lifetimes are not known and does not require accounting for all of the branches. We are analyzing Fourier Transform spectra from NIST and from the National Solar Observatory data archive at Kitt Peak via this technique, seeking to increase the set of known transition probabilities for Ce I by a factor of 2-3. A summary of results obtained to date will be presented.

\(^1\)St. Olaf College acknowledges support from NIST through its Measurement Science and Engineering grant program.

Q1.00007 Ag-Pb Interaction and Enhanced Fluorescence Emission of Pb\(^{2+}\) in Lead Borate Glasses\(^1\), SAIJASUDHA MALLUR, PRAKASH GIRI, MAHENDRA DC, P.K. BABU, Western Illinois University — We carried out Pb\(^{2+}\) fluorescence measurements in lead borate glasses and studied the effect of adding Ag into the base glass. Lead borate glasses containing Ag (0 and 3 mol\%) were prepared by the usual melt quench method. The prepared glasses were then annealed near the glass transition temperature (400 °C) at 5, 10, 20 and 30h. Fluorescence spectra of all these samples were obtained using different excitation wavelengths. In general, Pb\(^{2+}\) monomers are expected to have emission at wavelength less than 400nm. However, no emission in this region was observed due to the base glass absorption. The emission observed at 450nm is attributed to \(^{1}P_{1} \rightarrow ^{1}S_{0}\) transition of Pb\(^{2+}\) ions in dimer centers. Addition of Ag enhances the Pb\(^{2+}\) luminescence intensity at 450 nm which also shows an increase with the annealing time. The possible mechanisms for the fluorescence enhancement in the present glass could be the energy transfer from isolated Ag particles and local field effects due to the difference between the dielectric functions of the glass matrix and the silver particles.

\(^1\)This work was supported by National Natural Science Foundation of China under Grant No. 11074022 and No.11164022.
Q1.00008 Spectroscopic investigation of the $\Lambda$ and 3 $1\Sigma^+$ states of $^{39}\text{K}^{85}\text{Rb}$, JIN-TAE KIM, Dept. of Photonic Eng., Chosun Univ., Korea, YONGHOON LEE, Dept. of Chemistry, Mokpo National Univ., Korea, BONGSOO KIM, Dept. of Chemistry, KAIST, Korea, DAJUN WANG, PHILLIP GOULD, EDWARD EYLER, WILLIAM SWTALLEY, Dept. of Physics, Univ. of Connecticut, USA — We have explored the absorption spectra of ultracold $^{39}\text{K}^{85}\text{Rb}$ molecules in the region 11,000-12,000 cm$^{-1}$ above the ground state dissociation limit, formed by radiative decay following photoassociation (PA) to either the $3(0^-\text{F})$ or the $3(0^-\text{P})$ state. Recently we have reported that molecules formed by using the $3(0^-\text{P})$ PA level are not excited to the $\Lambda$ and 3 $1\Sigma^+$ states, but rather the 1 $1\Pi$, 2 $2\Sigma^+$, and 6 $1\Pi$ states. However, we have observed high vibrational levels of these 1 $\Sigma^+$ states by using the $3(0^-\text{F})$ level for PA. The absence of the $1 \Sigma^+$ states in the spectra from levels formed by the $3(0^-\text{P})$ PA level has been explained by considering Hund’s case (c) selection rules and the transition dipole moment calculations by Kotochigova et al.[1] between the upper excited $\Lambda 1\Sigma^+ (2(0^+))$ state and the three $\Omega$ components at the ground state dissociation limit. Unexpectedly, many high vibrational levels ($v=26-52$) of the $3 1\Sigma^+$ state, with a small transition dipole moment from the $1(0^-\text{F})$ state[1], have also been observed. The observed energies of the $v=26-44$ levels match well with those observed from molecular beam experiments. Thus we have fully analyzed the $^{39}\text{K}^{85}\text{Rb}$ electronic states in the entire region 11,000-12,000 cm$^{-1}$ above the ground state dissociation limit.


Q1.00009 X-ray diffraction assisted spectroscopy of Rydberg states, ADAM KIRRANDE, Harvard-Smithsonian CFA — X-ray diffraction combined with conventional spectroscopy could provide a powerful means to characterize excited atoms and molecules. We demonstrate theoretically how X-ray diffraction from laser excited atoms can be used to determine electronic structure, including angular momentum composition, principal quantum numbers and configuration (channel populations). A theoretical formalism appropriate for highly excited atoms, and easily extended to molecules, is presented together with numerical results for Xe and H atoms.

Q1.0010 Ab Initio Study of High-Lying Doubly Excited States of Helium in Static Electric Fields: Complex-Scaling Generalized Pseudospectral Method in Hyperspherical Coordinates, JOHN HESLAR, National Taiwan University, Taiwan, SHIH-I CHU, University of Kansas — We present a new complex-scaling (CS) generalized pseudospectral (GPS) method in hyperspherical coordinates (HSC) for ab initio and accurate treatment of the resonance energies and autoionization widths of two-electron atomic systems in the presence of strong dc electric field. The GPS method allows non-uniform and optimal spatial discretization of the two-electron Hamiltonian in HSC with the use of only a modest number of grid points. The procedure is applied for the first precision calculation of the energies and autoionization widths for the high-lying $5^1\Sigma^+$, $5^1\Pi^+$, $5^1\Delta^+$ and $5^1\Phi$ ($n=10$ to $20$) doubly-excited resonance states of He atoms. In addition, we present the first theoretical prediction of the energies and widths of high-lying doubly-excited resonance states of $1^1\Phi^+$ ($n=8$-$15$) in external dc electric field strengths of $3.915$-$10.44$ kV/cm. The calculated dc-field perturbed high-lying resonance energies are in good agreement with the latest experimental data.

Q1.00011 Landau-Zener crossings in magnetically trapped polar molecules, BENJAMIN STUHL, MARK YEO, MATT HUMMON, JUN YE, JILA / University of Colorado and NIST — Paramagnetic polar molecules generically exhibit a number of avoided crossings between Zeeman manifolds of opposite parities in combined magnetic and electric fields. In the context of a magnetic trap, these avoided crossings become opportunities for molecules to Landau-Zener hop to untrapped states. We have observed this behavior in a model system, magnetically trapped OH and achieve near-quantitative agreement with a simple Landau-Zener theory.

Q1.00012 PHOTON INTERACTIONS WITH ATOMS, IONS, AND MOLECULES III —

Q1.00013 THE IRON PROJECT & THE IRON OPACITY PROJECT: Re-establishing the Sun as the Astrophysical Rosetta Stone, ETHAN PALAY, SULTANA NAHAR, ANIL PRADHAN, MARC PINCONSOAULT, Ohio State U, JAMES BAILEY, Sandia Natl Lab — The aims of the two projects are detailed studies of radiative and collisional processes of astrophysically abundant atoms and ions, mainly iron and iron-peak elements, over a wide energy range, from infra-red to X-rays. The procedure is applied for the first precision calculation of the energies and autoionization widths of two-electron atomic systems in the presence of strong dc electric field. The GPS method allows non-uniform and optimal spatial discretization of the two-electron Hamiltonian in HSC with the use of only a modest number of grid points. The procedure is applied for the first precision calculation of the energies and autoionization widths for the high-lying $5^1\Sigma^+$, $5^1\Pi^+$, $5^1\Delta^+$ and $5^1\Phi$ ($n=10$ to $20$) doubly-excited resonance states of He atoms. In addition, we present the first theoretical prediction of the energies and widths of high-lying doubly-excited resonance states of $1^1\Phi^+$ ($n=8$-$15$) in external dc electric field strengths of $3.915$-$10.44$ kV/cm. The calculated dc-field perturbed high-lying resonance energies are in good agreement with the latest experimental data.

Q1.0014 X-ray dose absorption for medical applications, SARA LIM, Ohio State University, MAXIMILIANO MONTENEGRO, Universidad Catolica de Chile, SULTANA NAHAR, ANIL PRADHAN, ROLF BARTH, ROBIN NAKKULA, ERICA BELL, Ohio State University, YAN YU, Thomas Jefferson University — Interaction of high-Z (HZ) elements with X-rays occurs efficiently at specific resonant energies. Cross sections for photoionization rapidly decrease after the K-edge: higher energy X-rays are mostly Compton-scattered. These features restrict the energy range for the use of HZ moieties for radiosensitization in cancer therapy. Conventional X-ray sources such as linear accelerators (LINAC) used in radiotherapy emit a broad spectrum up to MeV energies. We explore the dichotomy between X-ray radiotherapy in two ranges: (i) $E < 100$ keV including HZ sensitization, and (ii) $E > 100$ keV where sensitization is inefficient. We perform Monte Carlo numerical simulations of tumor tissue embedded with platinum compounds and gold nanoparticles and compute radiation dose enhancement factors (DEF) upon irradiation with 100 kV, 170 kV and 6 MV sources. Our results demonstrate that the DEF peak below 100 keV and fall sharply above 200 keV to very small values. Therefore most of the X-ray output from LINACs up to the MeV range is utilized very inefficiently. We also describe experimental studies for implementation of option (i) using Pt and Au reagents and selected cancer cell lines. Resultant radiation exposure to patients could be greatly reduced, yet still result in increased tumoricidal ability.
Q1.00015 Inner shell resonances in the outer shell photoionization of Xe@C_{60}. MIRON AMUSIA, Racah Institute of Physics, Hebrew University, Jerusalem, Israel, LARISSA CHERNYSYHEVA, Ioffe Physical-Technical Institute, St.-Petersburg, Russia — Fullerenes C_{60} can be stuffed by almost all atoms A or even simple molecules. It is demonstrated by the example of the 5p-subshell of the Xe atom stuffed inside the C_{60} fullerene, i.e. the endohedral Xe@C_{60} that the so-called confinement resonances in 4d subshell strongly affect the absolute and differential in the photoelectron emission angle cross-section of 5p electrons photoionization in the region of 4d ionization threshold. It is a sort of a surprise that the narrow inner shell resonances are not smeared out in the outer shell photoionization cross-section. Inner shell resonances affect the outer cross-section by enhancing this enormously and modifying 5p dipole and non-dipole angular anisotropy parameters. Close to its own photoionization threshold, 5p photoionization cross-section of Xe@C_{60} is dominated by its own confinement resonances greatly enhanced by the intensity of incoming radiation due to polarization of the C_{60} electron shell by the incoming photon beam. In between, the 4d and 5p thresholds, the effect of 4d is becoming stronger while own resonances of 5p are becoming less and less important.

Q1.00016 MEMS-Based Beam Steering for Individual Addressing of Trapped Ions, STEPHEN CRAIN, EMILY MOUNT, CALEB KNOERNERSCHILD, TAEHYUN KIM, SOYOUNG BAEK, PETER MAUNZ, JUNGSANG KIM, Fitzpatrick Institute for Photonics, Electrical and Computer Engineering Department, Duke University — The ability to address individual ions in a long linear chain with multiple beams is necessary in order to realize scalable quantum information processing with trapped ions. Microelectromechanical systems (MEMS) technology allows one to design movable micromirrors to focus laser beams on individual ions and steer the focal point in two dimensions. This system provides low optical loss across a broad wavelength range and can easily scaled to multiple beams. Our current MEMS system is designed to steer a far-detuned UV pulsed laser beam to carry out single and two qubit Raman gates on a chain of Yb ions, with a waist of 1.5 μm across a 20 μm range. The crosstalk between neighboring ions can be used to characterize the individual addressing fidelity in this setup. We also present a MEMS-based optical shutter that utilizes the fast switching speeds of the MEMS devices without introducing thermal instability or frequency shifts of the beam. The shutter system is comprised of input and output UV fibers with collimating microlenses, a focusing lens, and a single MEMS mirror. By tilting the MEMS mirror, the beam is steered off the output fiber and the light is decoupled. We show a high extinction ratio of >90dB with a throughput of 53% and a switching speed of ∼2 μs.

Q1.00017 Linear chains in a monolithic symmetric trap for quantum information processing1, FAYAZ SHAIKH, RICHARD SLUSHER, Georgia Tech Research Institute, QUANTUM INFORMATION SYSTEMS TEAM — Linear ion chains are being used1 to simulate quantum magnet Ising interactions, phase transitions, and spin frustrations. We will present results for trapping linear ion chains in a monolithic two-level trap that utilizes the flexibility, complexity and scalability provided by VLSI silicon microfabrication. This trap provides optimized features and dimensions for trapping equally spaced ion chains while minimizing light scattering and exposed dielectrics that sometimes limit surface electrode ion traps. The ion chains are trapped symmetrically between two electrode layers. This geometry provides a strong pseudopotential well and radial field symmetry, resulting in stable ion mode frequencies and chains.


3This work is supported by the DARPA OLE program under ARO award W911NF-07-1-0576.

Q1.00018 Enhanced Single-Photon Multi-Detachment in Anions of C_{60} and Observation of a Scaling Law1, R.C. BILODEAU, M. HOENER, N. BERRAH, Western Michigan U., Kalamazoo MI, S. SCHIPPERS, A. MULLER, Justus-Liebig-Universität, Giessen, D.A. ESTEVES, R.A. PHANEUF, U. of Nevada, Reno NV, N.D. GIBSON, C.W. WALTER, Denison OH, A. AGUILAR, LBNL-ALS, Berkeley CA, J.M. ROST, Max-Planck-Institut, Dresden — Absolute single-photon multi-detachment cross sections in C_{60} have been measured. We observe a large enhancement (2 and 2.5 times for double and triple detachment, respectfully) of the oscillator strength in the anion compared to neutral C_{60}. Although the anion spectra is qualitatively similar to that of multi-photoionzation in C_{60}, the anion spectra are substantially compressed in photon energy. The effect of the additional screening provided by the excess electron in the anion on the knock-off process is proposed in order to explain the observed energy scaling. We can also deduce from the results that plasmon resonances do not couple strongly into two- and three-electron removal channels in either the anion or the neutral systems, a surprising result given the intrinsic multi-electron character of the plasmon resonances.  

[1] This work is funded by DOE, Office of Science, BES, Chemical Sciences, Geosciences and Biosciences Divisions. NDG and CWW acknowledge support from NSF, Grant No. 0757976. AM and SS acknowledge support from Deutsche Forschungsgemeinschaft.

Q1.00019 Double Photoionization of Helium Atom using effective Charges, HARI P. SAHA, University of Central Florida, Orlando, FL 32816 — We will report the results of our investigation on double photoionization of helium atom using the recently extended MCHF method [3] for double photoionization of atoms. Calculation will be performed using wave functions for the initial and the final states with and without the electron correlation. The initial state wave function will be calculated using both the HF and MCHF methods The final state wave functions will be obtained using the asymptotic effective charge [2,3] to represent the electron correlation between the two final state continuum electrons. Using these wave functions, the triple differential cross sections will be calculated for 30 eV excess photon energy. The single and total integral cross sections will be obtained for photon energies from threshold to 300 eV. The results will be compared with the available experimental and the theoretical data.


Q1.00020 Coupled channel theory of photoionization microscopy1, LIBO ZHAO, ILYA FABRIKANT, University of Nebraska, JOHN DELOS, College of William & Mary, FRANCK LEPINE, CHRISTIAN BORDAS, Laboratoire UMR CNRS, SAMUEL COHEN, University of Ioannina — A quantum mechanical coupled-channel theory is presented to simulate spatial distributions of electron probability density and current density, produced in photoionization of nonhydrogenous atoms in a uniform external electric field and recorded on a position-sensitive detector. Coupled equations for the monomulticomponent wavefunction are solved in mixed semiparabolic and parabolic coordinates. Using the theory, we predict distributions of electron probability density and current density produced in photoionization of the ground-state Li atom. The computed results are compared with experimental and very good agreement is found. The atomic core produces a significant effect in the electron probability density distribution in the vicinity of Stark resonances. The quantum tunneling effects in the presence of the atomic core are also analyzed.

1Supported by NSF.
Dramatic quadrupole effects in the low energy photoionization of the 4s subshell of free and confined Ca. SINDHU KANNUR, GAGAN B. PRADHAN, JOBIN JOSE, HARI R. VARMA, IIT-Mandi, PRANAWA C. DESHMUKH, IIT-Madras, STEVEN T. MANSON, Georgia State University — The importance of first-order nondipole effects in low-energy photoionization is well known [1], and the significance of second-order \( [\alpha^{(2)}] \), where \( k \) is the photon wave number nondipole terms has been stressed even at photon energies as low as \( \sim 11 \) eV [2]. In the present work, valence dipole and quadrupole photoionization of free atomic Ca and \( \text{Ca}^+ \) (Ca atom trapped in a \( \text{C}_{60} \) cage) are investigated using the relativistic random phase approximation (RRPA) [3]. In the vicinity of the 4s Cooper minimum (\( \sim 10 \) eV) [4], second-order nondipole terms are found to induce dramatic changes in the photoelectron angular distribution over a small energy range, primarily due to contributions from quadrupole-quadrupole interference. Also, the calculation of the dipole angular distribution parameter \( \beta \) in the vicinity of the dipole Cooper minimum requires the inclusion of the quadrupole terms, as was found earlier [2]. Finally, the results show that confinement of the Ca atom in the fullerene cage augments the quadrupole effects still further.


Observation of Bound-Bound Transitions in the Negative Ion of Lanthanum \( \text{La}^– \). C.W. WALTER, N.D. GIBSON, D.J. MATYAS, A.N. LEBOVITZ, Denison University, Granville, OH, K.J. LIEBL, Oberlin College, Oberlin, OH — The negative ion of lanthanum has been investigated with tunable infrared laser photodetachment spectroscopy. The relative signal of neutral atom production was measured with a crossed laser-ion beam apparatus over the photon energy range \( 0.29 – 6.0 \) eV. The spectrum reveals a number of sharp peaks due to bound-bound electric-dipole transitions in \( \text{La}^– \), observed here through a two-step process of excitation followed by photodetachment of the upper state. The transitions responsible for four of the peaks are identified through comparison to the calculations of O’Malley and Beck [1]. The richness of the observed bound state spectrum is unprecedented for atomic negative ions, and it highlights the uniqueness of \( \text{La}^– \) for applications such as laser cooling.


Fourier photospectroscopy of \( \text{Xe@C}_{60} \) in the \( \text{Xe} 4d \) giant resonance region: Testing the single-photoionization theory against recent measurements. AAKASH PATEL, HIMADRI CHAKRABORTY, Chemistry and Physics, Northwest Missouri State University, Maryville, MO have developed a technique, based on Fourier-transforming cross sections to the reciprocal configuration space, to explore the electronic multiple interferences in the photoionization of endohedral fullerene molecules. Using this technique, the single-photoionization cross section of endohedral \( \text{Xe@C}_{60} \) over \( \text{Xe} 4d \) giant resonance energy region, calculated in the time dependent local density approximation (TDLDA), is compared with recent double photoionization experimental data [1]. The analysis of oscillatory cross sections derives a number of inherent similarities between the prediction and the data, including a large beating-type oscillation and several others of intermediate size [2]. Results stress the need for more accurate measurements to access the wealth of information about the geometry of the system.


Photoionization of the \( \text{Zn@C}_{60} \) endofullerene: Atom-fullerene ground-state orbital hybridization of d-d character. JAYKOB MASER, Northwest Missouri State University, MOHAMMAD JAVANI, Georgia State University, RUMA DE, Northwest Missouri State University, MOHAMED MADJET, CFEL/DESY, Hamburg, Germany, HIMADRI CHAKRABORTY, Northwest Missouri State University, STEVE MANSON, Georgia State University — A detailed theoretical study of the shell photoionization of \( \text{Zn} \) endohedrally confined in \( \text{C}_{60} \) has been performed. The fullerene molecular core of \( \text{Zn} \) is modeled by a classical jellium smearing, while the delocalized cloud of 240 carbon valence electrons, \( \text{Zn} \) plus the encaged \( \text{Zn} \) atom placed at the center of the cage, are treated in the time-dependent local density approximation (TDLDA) [1]. A powerful hybridization of the \( \text{Zn} 3d \) state with the \( 2d \) orbital near the low end of \( \text{C}_{60} \) electronic band is unraveled. Cross sections for these hybrid states at both low photon energies, overwhelmed by electronic collective motions, and high energies of dominant single-electron behavior are presented. The results exhibit rich structures and are radically different from the cross sections of free atomic or free fullerene states participating in the hybridization process.


Ultrafast Energy Transfer between Oxygen Molecules. F.P. STURM, B. GAIRE, I. BOCHAROVA, P. BRÄUN, A. BELKACEM, TH. WEBER, Lawrence Berkeley National Laboratory, W. CAO, I. BEN-ITZHAK, Kansas State University, M. HONIG, J.B. WILLIAMS, A. LANDERS, Auburn University, R. DÖRNER, Goethe Universitats Frankfurt — Photo ionization of atoms or molecules just above the double ionization threshold often leaves the cation in an excited state. The excess energy is mainly released by autoionization or radiative decay. For dimers Cederbaum et al. have predicted a third process for relaxation. Here, the excited atomic or molecular target transfers the energy in form of a virtual photon to its neighboring partner, which emits an electron subsequently. The remaining doubly charged dimer then undergoes a Coulomb explosion. The effect is known as Interatomic Coulombic Decay (ICD) and has been observed for a variety of atoms so far. Only recently it was found to take place in water molecules as well. We report on the experimental study of this ultrafast energy transfer process in oxygen dimers.

1. Supported by the Division of Chemical Sciences, Office of Basic Energy Sciences, Department of Energy.
Q1.00027 Dissociation Dynamics and Molecular Imaging of Methane following Photoionization at the Carbon K-Edge
J.B. WILLIAMS, A.L. LANDERS, Auburn University, C. TREVISAN, California Maritime Academy, T. JAHNKE, M.S. SCHEFFLER, R. DOERNER, Frankfurt University, I. BOCHAROVA, F. STURM, C.W. MCCURDY, A. BELKACEM, TH. WEBER, Lawrence Berkeley National Laboratory — We have used Cold Target Recoil Ion Momentum Spectroscopy (COLTRIMS) to measure the momenta of the photoelectron and the molecular fragments arising from the dissociation of methane following core photoionization and subsequent Auger decay. We present results here that show (1) the full 3-D imaging of the molecule by the molecular frame photoelectron angular distribution; (2) the numerous dissociation pathways emerging from the unstable di- and tri-cations; (3) the dynamics associated with Jahn-Teller distortions in the breakdown of axial recoil behavior, where protons are only ejected along ground-state bond axes under certain conditions; and (4) the use of symmetries to improve statistics associated with measurements of this type. These results are compared with and interpreted through the use of Complex Kohn variational calculations.

Q1.00028 Theory of laser-dressed resonant Auger decay for ultraintense and ultrashort x rays
ANTONIO PICON, GILLES DOUMY, STEPHEN SOUTHWORTH, LINDA YOUNG, CHRISTIAN BUTH, Argonne National Laboratory — The emerging x-ray free electron lasers (FELs) such as the Linac Coherent Light Source (LCLS) at SLAC National Accelerator Laboratory can reach very high x-ray intensities and ultrashort pulse durations. We develop a theory for the strong coupling of x rays with an atom, which couples core electrons with Rydberg states. In addition, we consider a near-infrared (NIR) laser that couples the Rydberg states among each other. We can theoretically describe several atomic systems with this setup using three-level (L-type and cascade-type are considered) models, which allow us to use electromagnetically induced transparency for x rays induced by the NIR laser. The theoretical models also allow us to calculate the NIR-laser-controlled Auger electron spectrum. We apply these models to predict the Auger electron spectrum of Ne (L-type) and Ne\textsuperscript{+} (cascade-type). This work opens up new prospects to study and analyze the interaction of ultraintense and ultrashort x rays with atoms.

Q1.00029 Laser-Induced Electron-Positron Pair Creation — Relevance of Phase Effects
KATARZYNA KRAJEWSKA, JERZY KAMIŃSKI, Institute of Theoretical Physics, University of Warsaw — With recent technological progress and experimental availability of extremely powerful lasers, yielding a ponderomotive energy shift of the order of magnitude \( m_n c^2 \) and beyond, it has become of interest to reexamine fundamental processes of quantum electrodynamics (QED); in particular, the formation of electron-positron pairs by means of laser radiation [1]. The electron-positron pair creation in collisions of a relativistic nucleus with a two-color laser field is investigated using the standard approach of QED [2]. We consider the case when both components of the laser field have commensurate frequencies and comparable strengths. We analyze the dependence of both the angular distributions of created particles and the total probability rates of pair production on a phase coherence of a driving laser field.


Q1.00030 Exploring the high-order harmonic generation from Rydberg states with a fixed Keldysh parameter
ERDI ATA BLEDA, ILHAN YAVUZ, ZIKRI ALTUN, Marmara University, TÜRKER TOPCU, Auburn University — The commonly adopted viewpoint that the Keldysh parameter \( \gamma \) determines the dynamical regime of ionization in strong field physics has long been demonstrated to be a misleading one. One can then ask what happens in strong field ionization as relevant parameters, such as laser intensity and frequency, are varied while keeping \( \gamma \) fixed. We present results from our simulations of high-order harmonic generation (HHG) from Rydberg states of a hydrogen atom. We calculate high harmonic spectra from various initial states with \( n \) up to 42, where the laser intensities and the frequencies are scaled from those for \( n = 1 \) in order to maintain a fixed Keldysh parameter \( \gamma < 1 \). We find that as we go up in \( n \) for a fixed \( \gamma \), the position of the cut-off scales as \( \sim 1/n^2 \) in terms of the cut-off law predicted by the three-step model for \( n = 1 \). However, a secondary cut-off structure forms below this, which moves to lower harmonics as \( n \) is increased. This second cut-off splits the plateau into two regions, one higher in yield and below the second cut-off, and the second with lower yield following it. We further investigate the final \( n \)-distributions for some of the interesting cases to elucidate the physical mechanism leading to this structure.

1This work was supported by the Polish National Science Center, under Grant No. UMO-2011/01/B/ST2/00381.

Q1.00031 Precision treatment of single and double multiphoton ionization of He atoms by strong laser fields: Time-dependent generalized pseudospectral method in internal coordinates
DMITRY A. TELNOV, St. Petersburg State University, Russia, JOHN HESLAR, National Taiwan University, Taiwan, SHIH-I CHU, University of Kansas — We have developed a new computational method for accurate and efficient numerical solution of the time-dependent Schrödinger equation for two-electron atoms. Our approach is full-dimensional and makes use of the internal coordinates of the electrons in the plane defined by the electrons and the nucleus (\( r_1, r_2 \) and \( \theta_{12} \)) as well as Euler angles which determine the orientation of the plane in space. The internal coordinates can be optimally discretized by means of the generalized pseudospectral method while the Euler angles appear through the basis set functions with the definite total angular momentum and its projections.

Q1.00032 Density-Functional Theory with Optimized Effective Potential and Self-Interaction Correction for the Double Ionization of He and Be Atoms
DMITRY TELNOV, St. Petersburg State University, Russia, SHIH-I CHU, University of Kansas — We present a self-interaction-free (SIC) time-dependent density-functional theory (TDDFT) for the treatment of double ionization processes of many-electron systems. The method is based on the Krieger-Li-Iaf rate (KLI) treatment of the optimized effective potential (OEP) theory and the incorporation of an explicit self-interaction correction (SIC) term. In the framework of the time-dependent density functional theory, we have performed 3D calculations of double ionization of He and Be atoms by strong near-infrared laser fields. We make use of the exchange-correlation potential with the integer discontinuity which improves the description of the double ionization process. We found that proper description of the double ionization requires the TDDFT exchange-correlation potential with the discontinuity with respect to the variation of the spin particle numbers (SPN) only. The results for the intensity-dependent probabilities of single and double ionization are presented and reproduce the famous “knee” structure.

1This work was partially supported by DOE and NSF and by DOE-NTU-Taiwan.
**Q1.00034 Strong-field control of coherent anti-Stokes Raman scattering in iodine vapor with shaped ultrashort laser pulses**. MARTIN BITTER, University of British Columbia, Physics & Astronomy, EVGENY A. SHAPIRO, VALERY MILNER, University of British Columbia, ULTRAFAST COHERENT CONTROL GROUP TEAM — Extensive work has been done to investigate molecular dynamics in weak laser fields. In contrast, our understanding of molecular behavior and the possibilities to control it with strong laser pulses is still limited. In this work, we investigate the process of coherent anti-Stokes Raman scattering (CARS) in iodine vapor for different strong-field regimes. Saturation of the CARS signal with increasing pulse intensities is observed and studied both experimentally and theoretically. We show that it is possible to overcome this saturation by implementing different schemes of coherent control based on the technique of femtosecond pulse shaping. Optimal regimes for enhancing molecular CARS response to strong-field excitation are proposed and demonstrated, paving the way to more effective nonlinear spectroscopy.

**Q1.00035 X-ray–optical cross correlator for gas-phase experiments at the LCLS free-electron laser**. SEBASTIAN SCHORB, LCLS, SLAC National Accelerator Laboratory, T. GORKHOVER, Technische Universität Berlin, J.P. CRYAN, J.M. GLOWNIA, M.R. BIONTA, R.N. COFFEE, LCLS, SLAC National Accelerator Laboratory, B. ERK, R. BOLL, C. SCHMIDT, D. ROLLES, A. RUDENIKO, Max-Planck Advanced-Student Group at CFEL, A. ROUZEE, Max-Born-Institute Berlin, M. SWIGGERS, S. CARRON, J.-C. CASTAGNA, J.D. BOZEK, M. MESSERSCHMIDT, W.F. SCHLOTTER, C. BOSTEDT, LCLS, SLAC National Accelerator Laboratory — X-ray–optical pump–probe experiments at the Linac Coherent Light Source (LCLS) have so far been limited to a time resolution of 280 fs fwhm due to timing jitter between the accelerator-based free-electron laser (FEL) and optical lasers. We have implemented a single-shot cross-correlator for femtosecond x-ray and infrared pulses. An independent reference experiment relying only on the pulse arrival time information from the cross-correlator shows a time resolution better than 50 fs fwhm (22 fs rms) and also yields a direct measurement of the maximal x-ray pulse length. The improved time resolution enables ultrafast pump–probe experiments with x-ray pulses from LCLS and other FEL sources. Reference: S. Schorb et al., Appl. Phys. Lett. 2012 in press.

**Q1.00036 Moving towards strong-field femtosecond control of bond cleavage and charge localization in triatomic molecules**. BETHANY JOCHIM, U. ABLIKIM, M. ZOHRAHI, B. GAIRE, K.D. CARNES, B.D. ERSY, I. BEN-ITZHAK, J. R. Macdonald Laboratory, Department of Physics, Kansas State University, Manhattan, KS 66506 — A 3-D momentum imaging technique is employed to study intense ultrafast laser-induced dissociation of triatomic molecular ions from an ion beam. Utilizing our measured kinetic energy release and angular distribution spectra along with the calculated electronic structure of these molecules, we elucidate possible dissociation pathways and anticipate and explore various laser parameters that could be used to drive transitions to specific final products. For example, we have studied Na₂O⁺, in which we find that for typical intense IR laser pulses (∼30 fs, transform-limited, 800 nm, ∼10¹⁵ W/cm² pulses), the preferred bond cleavage (i.e., breaking the N-N bond vs. the N-O bond) and charge localization patterns are those that are the most energetically favorable. We investigate laser parameters that could be used to steer this and other systems to less likely outcomes.

**Q1.00037 DC and subcycle-resolved AC Stark shifts in Helium**. AIHUA LIU, U. W. THUMM, Kansas State University — We are developing a finite element discrete variable representation (FE-DVR) code to model the response of two-electron atoms and two-electron ions to ultra-short pulses of EM radiation. Our first numerical results for the DC Stark shift of helium deviate significantly from previous [1] single-active-electron (SAE) but are in close agreement with improved SAE calculations that include the effect of core polarization in the external field. For 3×10¹⁴ W/cm² infrared red fields, we calculate sub-IR-cycle- resolved instantaneous (AC) level shifts of low-lying bound He states that also strongly deviate from the SAE prediction [1]. We plan to apply our code to model recently measured subcycle time-resolved absorption spectra [2].

1Supported by the Chemical Sciences, Geosciences and Biosciences Division, Office of Basic Energy Sciences, Office of Science, U.S. Department of Energy.

2Supported by the US DOE and NSF.

**Q1.00038 Toward understanding the breakup mechanism of triatomic molecular ions in an intense laser field**. UTUQ ABLIKIM, MOHAMMAD ZOHRAHI, BETHANY JOCHIM, KEVIN CARNES, ITZIK BEN-ITZHAK, J. R. Macdonald Laboratory, Department of Physics, Kansas State University, Manhattan, KS 66506 — Studies of laser-induced dissociation and ionization of triatomic molecular ions is a key step toward understanding the breakup mechanisms of complex systems in an intense laser field. This study is focused on two questions: (1) Does a triatomic molecular ion XY₂⁺ bend during the interaction with a strong ultra-short laser field? (2) What is the preferred dissociation or ionization alignment relative to the laser polarization of such molecular ions? We implement a coincidence three dimensional momentum imaging technique, which allows us to measure all the neutral and charged fragments of any breakup channels of a triatomic molecular ion in coincidence. For example, we have studied a CO₂⁺ ion beam, exposing it to intense 30 fs, 790 nm laser pulses with intensity up to 10¹⁵ W/cm², in order to address the above questions.

1Supported by the Chemical Sciences, Geosciences and Biosciences Division, Office of Basic Energy Sciences, Office of Science, U.S. Department of Energy.
Q1.00039 Atomic hyperpolarisabilities and the non-linear optics of atomic gases\textsuperscript{1}, MICHAEL BROMLEY, The University of Queensland, BRANDON RIGSBEE, Kansas State University, JIM MITROY, Charles Darwin University — The properties of one and two-electron atoms are calculated numerically using configuration interaction and perturbative methods. We present calculations here the dynamic hyperpolarisabilities of these atoms, the emphasis here being on low-energy fields of interest in atomic clocks, and high-energy excitations that probe near Rydberg states. The variance of transition energies and magic wavelengths with hyperpolarisability will be discussed. Two forms of the susceptibilities, $\chi(omega, J)$, that describe the non-linear optics of atoms in electric fields, will be presented that describe the variation of the refractive index of an atomic gas in ground or excited states, as well as third-harmonic generation.

\textsuperscript{1}MB is supported by an Australian Research Council Future Fellowship (FT100100905) and previously National Science Foundation grants PHY-0970127 and CHE-0947087. JM is supported by an Australian Research Council Discovery Project DP-1092620.

Q1.00040 ATOMIC, MOLECULAR, AND CHARGED PARTICLE COLLISIONS III –

Q1.00041 Single- and Multiple-Electron Removal Processes in Proton-Water Vapor Collisions\textsuperscript{2}, MITSUKO MURAKAMI, TOM KIRCHNER, MARKO HORBATSCH, Department of Physics and Astronomy, York University, Toronto ON M3J 1P3, Canada, HANS JÜRGEN LÜDDE, Institut fuer Theoretische Physik, Goethe-Universitaet, D-60438 Frankfurt, Germany — Charge-state correlated cross sections for single- and multiple-electron removal processes due to capture and ionization in proton-H\textsubscript{2}O collisions are calculated by using the non-perturbative basis generator method adapted for ion-molecule collisions \textsuperscript{1}. Orbital-specific cross sections for vacancy production are evaluated using this method to predict the yields of charged fragments (H\textsubscript{2}O\textsuperscript{+}, OH\textsuperscript{+}, H\textsuperscript{+}, O\textsuperscript{+}) according to branching ratios known to be valid at high impact energies. At intermediate and low energies, we obtain fragmentation results on the basis of predicted multi-electron removal cross sections, and explain most of the available experimental data \textsuperscript{2}. The cross sections for charge transfer and for ionization are also compared with recent multi-center classical-trajectory Monte Carlo calculations \textsuperscript{3} for impact energies from 20keV to several MeV.

\textsuperscript{1}H.J. Lüdde et al, Phys. Rev. A 80, 060702(R) (2009)
\textsuperscript{3}C. Illescas et al, Phys. Rev. A 83, 052704 (2011)

Q1.00042 Elastic and Inelastic Collisions of Single Cs Atoms with an Ultracold Rb Cloud , FARINA KINDERMANN, Department of Physics, TU Kaiserslautern, NICOLAS SPETHMANN, DIETER MESCHEDE, IAP, Uni Bonn, ARTUR WIDERA, Department of Physics, TU Kaiserslautern — Ultracold gases doped with impurity atoms are promising hybrid systems that pave the way for investigation of a series of novel and interesting scenarios: They can be employed for studying polaron physics, the impurity atoms can act as coherent probes for the many-body system, and the coherent cooling of neutral atoms containing quantum information has been proposed. Here, we immerse single and few Cs atoms into an ultracold Rb cloud. Elastic collisions lead to rapid thermalization of both sub-systems, while inelastic collisions lead to a loss of Cs from the trap. When thermalized, the impurity atom is localized inside the Rb gas. The ultracold Rb gas remains effectively unaffected by the interaction with the Cs impurity atoms. The poster will present details of the experimental setup, sequence and data analysis needed to extract the interspecies scattering length and three-body loss coefficient from the thermalization dynamics and loss rates measured.

Q1.00043 Ionization in collisions between metastable hydrogen atoms\textsuperscript{1}, ALEX BOHR, ANDREW BLICKLE, STEPHEN PAOLINI, LUKE OHLINGER, ROBERT FORREY, Penn State University, Berks Campus — Associative and Penning ionization cross sections are calculated for collisions between metastable hydrogen 2s atoms at thermal energies. Cross sections for deuterium 2s collisions are also reported. The associative ionization cross sections behave as $E^{-2/3}$ for collision energy $E$, in agreement with an existing experiment. The Penning ionization cross sections dominate for all energies and are found to follow the $E^{-2/3}$ behavior that was predicted in previous work for the total ionization cross section. The magnitudes of our theoretical associative ionization cross sections for H(2s)+H(2s) collisions are between two and four times larger than the experimental data.

\textsuperscript{1}supported by NSF Grant No. PHY-0854838

Q1.00044 Transfer of atomic alignment in alkali systems, B. PATTON, O. NEITZKE, S. ROCHESTER, Department of Physics, UC Berkeley, E. BAHR, S. GUTTIKONDA, D.F. JACKSON KIMBALL, Department of Physics, CSU East Bay, B. COSTE, Institut Polytechnique de Grenoble, I. NOVIKOVA, Department of Physics, College of William & Mary, D. BUDKER, Department of Physics, UC Berkeley and Nuclear Science Division, Lawrence Berkeley National Laboratory — The well-known phenomenon of ‘spin exchange’ has been thoroughly characterized in alkali-alkali collisions, and atomic orientation is easily transferred between different alkali isotopes. Nevertheless, collisional transfer of higher-order polarization moments (such as atomic alignment) has received little attention in the literature. Such alignment transfer should be forbidden in sudden binary collisions of alkali atoms, but it is reasonable to question at what level. Here we discuss recent experiments to place limits on this alignment-exchange rate between isotopes of rubidium and cesium in a room-temperature vapor cell.

Q1.00045 Theoretical Studies of Dissociative Recombination of Electrons with N\textsubscript{2}H\textsuperscript{+} Ions\textsuperscript{1}, D.O. KASHINSKI, United States Military Academy, R.F. MALENDA, A.P. HICKMAN, Lehigh University, D. TALBI, Université Montpellier II — We are investigating the dissociative recombination (DR) of electrons with the molecular ion N\textsubscript{2}H\textsuperscript{+}. (The process is $e^- + N_2H^+ \rightarrow N_2 + H$.) $N_2H^+$ is found in the interstellar medium, and a better understanding of the DR process will aid the development of astrophysical models. For a quantitative DR study of $N_2H^+$, an even-handed treatment of the excited valence and Rydberg surfaces of $N_2H$ is required. We are currently performing large scale multi-reference configuration interaction (MRCI) electronic structure calculations to obtain these highly excited-state surfaces of $N_2H$. The effects of strong Rydberg-valence mixing in excited $N_2H$ are then disentangled to identify the primary dissociating surface that governs the DR process. This work is based on using the block diagonalization method to determine diabatic potential surfaces. The surfaces have been calculated at several different values of the NH distance and the NN–H bond angle. Preliminary results indicate that the direct method cross section is small at low energies which suggests the indirect method (or Renner-Teller effect) may play a role in the DR process. The current status of this work will be presented at the conference.

\textsuperscript{1}Work supported by the NSF, the XSEDE, and the USMA FDRF.
**Q1.00046** Electron Impact Ionization of He atom using screening potential. HARI P. SAHA, University of Central Florida, Orlando, FL 32816 — We will report the results of our investigation on electron impact ionization of helium atom using our extended MCHF method [1] for electron impact ionization of atoms. The initial state wave function will be calculated with both HF and MCHF approximations and the electron correlation between the two final state continuum electrons will be obtained using the screening potential [2-4]. Calculations will be made for triple differential cross sections for 4 eV excess energy sharing equally by the two final state continuum electrons. The results will be presented for all scattering angles and all kinetic energies. Comparison will be made with available experimental and theoretical data.


**Q1.00047** Resonances in slow electron collisions with In, Tl, Ga and At atoms: Accurate electron affinities1. ZINEB FELFLI, ALFRED Z. MZEZANE, Clark Atlanta University, DIMITRI SOKOLOVSKI, Queen’s University of Belfast, UK — The complex angular momentum (CAM)-calculated low-energy electron elastic total cross section (TCS) for In is benchmarked through its recently measured electron affinity (EA) [1]. The CAM method is then used to calculate the TCSs for Tl, Ga and At atoms. From the dramatically sharp resonances in the TCSs, binding energies (BEs) for Tl-, Ga- and At- formed during the collisions as Regge resonances are extracted and compared with the existing experimental and theoretical values. Notably, our calculated BE for the first excited state of Tl- agrees excellently with the EAs of [2, 3]. However, our EA for Tl is 2.415 eV. Consequently, we conclude that the published theoretical and experimental EAs for Tl correspond to the BE of the first excited state of Tl and not to the EA value. This calls for immediate experimental verification.


1Research supported by DOE, AFOSR and Army Research Office.

**Q1.00048** Electron-hydrogen cross section computation for astrophysical applications. JAKUB BENDA, KAREL HOUFK, Institute of Theoretical Physics, Faculty of Mathematics and Physics, Charles University in Prague — Our contribution focuses on the electron-hydrogen scattering and is intended as an extension of available atomic databases (e.g [1]) used by the astronomers and stellar/solar physicists. These databases often lack required precision and sometimes even major resonances, which are essential for correct transition rates extraction and thus for the description of astrophysical phenomena. Our aim is to obtain a controlled approximation of scattering cross section energy dependence for all relevant energies and (de)excitational transitions. The poster summarises results computed by freely available (e.g. [2, 3]) computer codes and compares them with our original results. Low energy cross sections – up to this time a domain of R-matrix packages – have been recomputed using exterior complex scaling implemented in B-splines (see [4]), whereas higher energies using different types of Born approximation.


**Q1.00049** Importance of final state electron-electron interactions in the Triple Differential Cross Sections for Electron Impact Ionization of Neon 1. S.M. AMAMI, DON MADISON, Missouri S&T, HARI SAHA, University of South Florida, THOMAS PFLUEGER, XUEGUANG REN, ARNE SENFTLEBEN, ALEXANDER DORN, JOACHIN ULLRICH, Max-Planck-Institute for Nuclear Physics, Heidelberg, Germany — Three-dimensional triple differential cross sections have been calculated and measured for 61eV electron-impact ionization of the 2p state of neon. Three-dimensional distributions for the ejected electron will be presented for a fixed incident projectile energy and scattered projectile angles ranging between 20 degrees and 70 degrees and ejected electron energies ranging between 2eV to 20eV. The theoretical model used for the calculations is the DWBA (distorted wave Born approximation). The importance of PCI (post collision interaction between the scattered and ejected electron) will be examined by either including or excluding this effect in the final state wavefunction. The importance of the interaction between the ejected electron and the residual atomic electrons will be examined by comparing results using distorted waves calculated in a static potential with Hartree-Fock distorted waves.

1Work supported by NSF under grant number PHY-1068237.

**Q1.00050** Electron-impact excitation of the electronic states of pyrimidine 1. MICHAEL BRUNGER2, DARRYL JONES, SUSAN BELLM, ARC Centre for Antimatter-Matter Studies, School of Chemical and Physical Sciences, Flinders University, GPO Box 2100, Adelaide, SA 5001 Australia, ARC CENTRE FOR ANTIMATTER-MATTER STUDIES TEAM — Pyrimidine (C4N2H2) is an important molecule, as it forms the basis of larger biomolecules, such as the DNA bases thymine, cytosine and uracil. There is a pressing demand for low-energy electron scattering data from such biological analogs in order to model radiation induced damage [1]. We therefore present the first measurements for absolute differential cross section data for low-energy electron-impact excitation of the electronic states of pyrimidine. The present measurements were performed using a crossed-beam apparatus [2] for incident electron energies ranging between 15 to 50eV while covering a 10 to 90° angular range. Here the absolute scale has been determined through a normalisation to the recently measured elastic scattering differential cross section data for pyrimidine [3].


1Institute for Mathematical Sciences, University of Malaya, Kuala Lumpur 50603, Malaysia
Q1.00051 Integral Cross Sections for Electron Impact Excitation of Rydberg and Valence States of Molecular Nitrogen, C.P. MALONE, P.V. JOHNSON, I. KANIK, Jet Propulsion Laboratory, X. LIU, Space Environment Technologies, B. AJDARI, M.A. KHAKOO, California State University, Fullerton — We present integral cross sections (ICSs) for electron impact excitation of N\(_2\) out of the ground state X\(^{(v=0)}\), to the b, c\(_1\), c\(_2\), b', c\(_{1}'\), c\(_{2}'\), and F electronic states at incident energies ranging between 17.5 eV and 100 eV. The ICSs were derived from the differential cross sections (DCSs) of Khakoo et al. [Phys. Rev. A 77, 012704 (2008)], which were obtained by unfolding energy loss spectra in the ~12-13.82 eV range. Recently, Heays et al. [Phys. Rev. A 85, 012705 (2012)] measured comparable higher resolution energy loss spectra, with a significantly different apparatus configuration, but in agreement with the Khakoo et al. (2008) spectra. This latter additional effort provided further confidence in the accuracy of the DCSs upon which the present ICS results are based. Of the higher-lying states studied, five are singlet states that radiate to the ground state via dipole allowed transitions. These include the b and b' valence states and the c\(_{1}'\) Rydberg state that give rise to the Birge-Hopfield I, II, and Carroll-Yoshino bands, respectively, all of which are observed in the atmospheres of Earth, Titan, and Triton. The c\(_{2}'\) and o\(_3\) Rydberg states give rise to the Worley-Jenkins and Worley series of Rydberg bands, respectively. However, these emissions are not readily observed since predissociation for the c\(_3\) and o\(_4\) states approaches 100%. As such, direct electron excitation measurements, such as those presented here are superior to standard (spontaneous) emission based measurements in this case.

Q1.00052 Nonlocal resonance model for two nuclear degrees of freedom\(^1\), MARTIN FORMANEK, KAREL HOUFEK, Institute of Theoretical Physics, Faculty of Mathematics and Physics, Charles University in Prague — A nonlocal resonance model (NRM) [W. Domcke, Phys. Rep. 208, 97 (1991)] is a commonly used method of calculating cross sections for elastic and inelastic processes in resonant electron-molecule collisions. Up to now, there has been a great number of studies devoted to implement this approach for molecules with only one nuclear degree of freedom (e.g. N\(_2\), H\(_2\), HCl etc) In the present work we developed a generalization of the NRM for two degrees of freedom. For testing purposes we have constructed two dimensional model, which captures essential features of resonant collisions of electrons with the CO\(_2\) molecule. Final cross sections for few chosen vibrational excitations are being compared with results obtained via a local complex potential approximation, which is so far the only approach dealing with multidimensional phenomena [C.W. McCurdy et al, Phys. Rev. A 67, 042708 (2003)]. We also discuss difficulties arising, when one chooses to work in a time dependent or a time independent formalism.

\(^1\)This work is supported by the Grant Agency of the Charles University in Prague (grant no. 424911)

Q1.00053 Breaking a tetrahedral molecular ion with electrons: Study of NH\(_4^+\)\(^1\), NICOLAS DOUGUET, University of California Davis, VIATCHESLAV KOKOULINE, University of Central Florida, ANN OREL, University of California Davis — We apply a general theoretical model to study the dissociative recombination of the polyatomic ion NH\(_4^+\). The high symmetry of the molecule, represented by the tetrahedral group, leads to complex vibronic couplings responsible for dissociative recombination. By applying multi-channel quantum defect theory and using symmetry considerations, we treat the doubly and triply degenerate modes and electronic states of NH\(_4^+\) to calculate a theoretical cross section which agrees well with existing experimental data. This represents, to our knowledge, the first DR study for a molecular ion with triply degenerate electronic states and normal modes.

\(^1\)This work is supported by the DOE Office of Basic Energy Science and the National Science Foundation, Grant No's PHY-08-55092 and PHY-08-55622.

Q1.00054 Experimental and theoretical investigation of the triple-differential cross sections for electron impact excitation-ionization of aligned H\(_2\) for different orientations of the molecule\(^1\), ESAM ALI, DON MADISON, Missouri S and T, ALLISON HARRIS, Henderson State University, JULIAN LOWER, Institut für Kernphysik, ERICH WEIGOLD, Australia National University, CHUANGANG NING, Tsinghua University — Most experiments measuring electron-impact ionization of molecules do not determine the orientation of the molecule at the time of ionization. One way to determine the orientation is to simultaneously ionize the molecule and excite the residual ion to a state that will dissociate. The orientation of the molecule can then be determined by detecting one of the dissociation fragments since the fragments will leave in the direction of orientation. Experimental and theoretical TDCS (triple differential cross sections) results will be presented for excitation-ionization of three excited states of H\(_2\) for three different orientations of the molecule at an incident electron energy of 176 eV.

\(^1\)Work supported by NSF under grant number PHY-1068237

Q1.00055 Comparison of positron and electron binding to molecules\(^1\), J.R. DANIELSON, A.C.L. JONES, M.R. NATISIN, C.M. SURKO, University of California, San Diego — Positrons can attach to molecules via Feshbach resonances in which a vibrational mode absorbs the excess energy. Using a high-resolution positron beam, this process has been used to measure positron-molecule binding energies for many chemical species\(^2\). In particular, recent measurements have focused on molecules with large permanent dipole moments (i.e., \(\mu > 2.5 \text{ D}\)), including aldehydes, ketones, and nitriles. Positron binding to these molecules is compared to the analogous weakly bound electron-molecule (negative-ion) states, commonly called "dipole-bound" states\(^3\). Positron binding energies are found to be on average two orders of magnitude larger than those of the negative ions due to two effects: the orientation of the molecular dipole moment allows the positron to approach it more closely; and for positrons, lepton correlations (e.g., via dipole polarizability) contribute more strongly. Comparisons to available calculations will be presented, as will comparisons to binding to molecules with \(\mu \sim 0\) (e.g., polarizability bound states).

\(^1\)Work supported by NSF grant PHY 10-68023.
Q1.00056 Positron Binding to Molecules: Interplay between permanent dipole moments and polarizability
A.C.L. JONES, J.R. DANIELSON, M.R. NATISIN, C.M. SURKO, University of California, San Diego — Energy resolved studies of positron-molecule collisions exhibit vibrational Feshbach resonances in annihilation, thus providing evidence that positrons can bind to these species. The downshifts of the observed resonances provide a measure of the positron-molecule binding energies which range from 1 to 300 meV. Presented here are annihilation spectra and binding energies for a wide range of chemical species, including aldehydes, ketones, formates, acetates, nitriles, alcohols, and halogenated compounds. Within a group, the measured binding energies often show an approximate linear correlation with molecular dipole polarizability. However, other effects, including the permanent dipole moment ($\mu$) and molecular geometry, play significant roles as well. For example, for compounds with $\mu \geq 2$ D, it appears that localization of the positron wave function leads to enhanced binding and an increased dependence upon both $\mu$ and electron-positron correlations. The relationship of these results to theoretical calculations is discussed.

Q1.00057 Statistical Multimode Resonant Annihilation of Positrons on Molecules
M.R. NATISIN, A.C.L. JONES, J.R. DANIELSON, C.M. SURKO, University of California, San Diego, G.F. GRIBAKIN, Queen’s University, Belfast — Annihilation at positron energies in the range of the molecular vibrational modes is dominated by large-amplitude vibrational Feshbach resonances (VFR) in which the positron attaches to the molecule. In small molecules, there is a quantitative description of the annihilation rates, $Z_{\text{eff}}$, due to the VFR. Here we focus on a broad spectrum of enhanced annihilation that is observed in the spectra of many, if not most, molecules. This spectral component, for example, dominates the spectra in small molecules with relatively large binding energies, such as CCl$_4$ and CBr$_4$. A model that assumes excitation and escape from a statistically complete ensemble of multimode vibrations is presented that reproduces key features of the data. Related issues of intramolecular vibrational redistribution (IVR), and the effects of escape channels on the primary VFRs will also be discussed.

Q1.00058 Dissociation-aided state preparation and spectroscopy of trapped molecular ions
JOAN MARLER, VAISHNAVI RAJAGOPAL, BRIAN ODOM, Northwestern University — Preparation of state-selective ensembles of cold molecules is a promising starting point for precision molecular spectroscopy. Ion traps provide an ideal environment for rovibrational cooling of diatomic molecules. Ion trap life times are typically greater than hours and the Coulomb force ensures long internal-state coherence times. Additionally, co-trapped and laser-cooled atomic species provide sympathetic translational cooling down to mK temperatures. The fluorescence of the co-trapped atomic species can be used as a diagnostic for molecule formation and dissociation, with additional flexibility arising when the dissociating atomic ion is the same species as the coolant ion. Presented here are prospects for this type of spectroscopy using a Barium ion trap.

Q1.00059 Progress In Doppler Cooling of SiO$^+$
JASON NGUYEN, DAVID TABOR, MARC BOURGEOIS, BRIAN ODOM, Northwestern University — The rich internal structure which makes molecular ions interesting is exactly what makes them difficult to Doppler cool. Rotation and vibration within the molecule results in additional dark states which require repumping, and higher-order processes such as photodissociation and predissociation may terminate the cycling transition. We have identified SiO$^+$ as a promising candidate for laser cooling, and we present our current experimental progress towards cooling both the external and internal degrees of freedom.

Q1.00060 A new shape resonance in the Ps$^-$ system
YEW KAM HO, Institute of Atomic and Molecular Sciences, Academia Sinica — There have been continues experimental and theoretical investigations on the positronium negative ion (Ps$^-$), one of the simplest three-lepton systems interacting through Coulomb forces. In the present work, we use highly correlated Hylleraas wave functions up to $N=1078$ terms together with employing the complex-coordinate rotation method to investigate resonances in the Ps$^-$ system. We have located a new Feshbach shape resonance lying above the Ps $(n=2)$ threshold. Our preliminary results for the resonance parameters are $E_0 = 0.0498788$ a.u. and $\Gamma / 2 = 0.0139470$ a.u., where $E_0$ and $\Gamma$ denote the resonance energy and width, respectively. This stabilized complex eigenvalue has never been reported in the literature, to the best of our knowledge. Here, by changing the mass of the positively charged particle from one unit of the electron mass to infinitely heavy, we have traced this resonance pole from the positronium negative ion to the hydrogen negative ion. Detailed calculations will be presented at the meeting.

1Work supported by NSF grant PHY 10-68023.
5Danielson, op. cit.

1Work supported by NSF grant PHY 10-68023.
2G. F. Gribakin, J. A. Young, C. M. Surko, Rev. Mod. Phys. 82, 2557 (2010).

1This work was supported by NSC of Taiwan, ROC.
Q1.00061 On thermalization of positrons in water vapour  
SRDJAN MARJANOVIC, ANA BANKOVIC, Institute of Physics Belgrade, University of Belgrade, Serbia, STEPHEN BUCKMAN, Centre for Antimatter-Matter Studies, Australian National University, Canberra, ACT, GUSTAVO GARCIA, Instituto de Física Fundamental, Consejo Superior de Investigaciones Científicas, Madrid, Spain, RONALD WHITE, Centre for Antimatter-Matter Studies, James Cook University, Townsville, Australia, MICHAEL BRÜNGER, Physics Department, Flinders University of South Australia, Adelaide, South Australia, MILOVAN SUVAKOV, GORDANA MALOVIC, SASA DJUKO, ZORAN LJ. PETROVIC, Institute of Physics Belgrade, University of Belgrade, Serbia — Water being the main component of the human tissue is the primary candidate for the basis of models describing positron diagnostics and therapy. Our calculations are based on the elementary binary cross sections measured or calculated. We use a Monte Carlo code following all individual collisions and trajectories allowing for the addition of external fields and accurate representation of non-conservative processes. In order to obtain realistic results completeness should be achieved for energy, momentum and number balances. Rather than determining transport coefficients which have only been measured in few cases for positrons we determine other observables. We determine the thermalization of a group of positrons released at a point in water vapour. The thermalization times may be scaled using Nt scaling. We also calculate the range of positrons, the corresponding diffusion coefficient and show shapes of individual trajectories. Finally we also establish the energy loss spectrum on the basis of binary processes. This allows us comparisons with other codes used to model transport of positrons.

Q1.00062 Charge Transfer, Ionization, and Excitation in Collisions between Protons and the Ions He\(^{+}\), Li\(^{2+}\), Be\(^{3+}\), B\(^{4+}\), and C\(^{5+}\)  
THOMAS WINTER, Penn State U., Wilkes-Barre Campus — Coupled-state cross sections are being determined for electron transfer, ionization, and excitation in collisions between keV- to MeV-energy protons and the hydrogenic ions He\(^{+}\), Li\(^{2+}\), Be\(^{3+}\), B\(^{4+}\), and C\(^{5+}\), extending work reported 25 years ago with a limited basis for electron transfer and ionization only, over a limited energy range below the peak in the ionization cross section the first and last processes [with the ions He\(^{+}\) and C\(^{5+}\)] were also considered in related studies. The presently used one- and two-center Sturmian bases are similar to those in the recent large-basis calculations for antiproton-H(1\(s\)) atom collisions. Detailed convergence studies are being carried out, and scaling rules with nuclear charge are being re-examined, as are connections with perturbative results for all three processes, including Born cross sections for excitation into individual lower excited states.

Q1.00063 Charge Transfer in Collisions between Molecular Ions and Atomic Hydrogen/Deuterium  
V.M. ANDRINANARJONIA, Department of Physics, Pacific Union College, Angwin CA 94508, USA, I.N. DRA-GANIC, Physics Division, Oak Ridge National Laboratory, Oak Ridge TN 37831, USA, D.G. SEELY, Department of Physics, Albion College, Albion, MI 49224, USA, C.C. HAVENER, Physics Division, Oak Ridge National Laboratory, Oak Ridge TN 37831, USA — Using the Oak Ridge National Laboratory ion–atom merged–beams apparatus, absolute cross sections of direct and dissociative charge transfer (CT) between H/D and different molecular ions (D\(^{2+}\), CO\(^{+}\), and O\(^{2+}\)) are measured from 20 eV/u to 2 keV/u collision energies. Toward high energy where the differences in Q-value of the reaction can be neglected and the rovibrational modes can be considered as frozen, the measured cross sections for the diatomic ions all converge to \((7 \pm 0.5) \times 10^{-16} \text{cm}^2\) at 2 keV/u and are consistent with a rovibrational frozen (H\(^{+}\), H) calculation (Physical Review A 84, 062716, 2011). Below one keV/u collision energy, the measured cross sections exhibit trends which are compared to previous merged-beams measurements of CT with H for atomic ions with a variety of electrons on the core.

Q1.00064 Ionization of Rydberg Atoms in Controlled Surface Electric Fields  
YU PU, BARRY DUNNING, Rice University — Earlier work shows that the ionization of xenon Rydberg atoms at metal surfaces is strongly influenced by the presence of stray patch fields. In the present work lithographically patterned electrode arrays comprising two interleaved “combs” are used to generate controlled surface electric fields by applying different potentials to each “comb.” Xenon ions produced near the surface are collected by an ion collection field applied perpendicular to the surface. With equal biases applied to the electrodes, the observed ion signal increases rapidly with increasing ion collection field above some threshold eventually saturating when each incident Rydberg atom is detected as an ion. Application of surface electric fields leads to a dramatic increase in the ion signal seen at low ion collection fields due to field ionization in the surface field well above the surface. The data are in good qualitative agreement with the predictions of a simple ionization model and suggest that such surface field ionization could allow efficient detection of low-n Rydberg atoms.

Q1.00065 QUANTUM OPTICS, MATTER OPTICS, AND COHERENT CONTROL III –

Q1.00066 Optimal Control Bounds of Molecular Orientations in Finite Temperatures  
SHENG-LUN LIAO, National Taiwan University, Taiwan, TAK-SAN HO, HERSCHEL RABITZ, Princeton University, SHIH-I CHU, University of Kansas — We investigated the optimal control bounds for the orientation of molecular systems in finite temperatures. The upper bounds of orientation controls are known to depend on both the temperature that determines the initial mixed states and the number of rotational states that can be excited by laser pulses. We considered the OCS molecule as an example to numerically demonstrate that a high degree of field-free-orientation can be achieved by optimally shaped pump fields in THz region \([1]\). To this end, we have implemented a fast monotonically convergent iterative procedure to obtain optimal orientation control pulses, by extending our recently formulated two-point boundary-value quantum control paradigm (TBQCP) for the pure-state optimal control problems \([2\text{-}4]\) to the mixed-state ones. It was found that the degree of orientation could achieve 0.83 dynamically, which is \(96\%\) of the kinematical maximum, at \(T=100K\).


\(1^{\text{st}}\) This work was partially supported by DOE and NSF and by MOE-NSC-NTU-Taiwan.
Q1.00688 Spin and motion entanglement of neutral atoms with optical frequency combs, QUANIA QURASHI1, VLADIMIR MALINOVSKY, JASON ALEXANDER, VIOLETA PRIETO, CHRIS ROWLETT, PATRICIA LEE, Army Research Laboratory — Optical frequency combs, emitted by ultrafast mode-locked pulsed lasers, are excellent tools to perform quantum coherent control. The spectral purity, large bandwidth and high pulse powers makes these sources attractive for precision control of multi-level atoms. We envisage using pairs of OFC modes to drive stimulated Raman transitions between the two hyperfine clock states of 87Rb confined on an atom chip. The Raman transitions will be driven using an optical, four photon technique, whereby the first photon pair drives off-resonantly to the intermediate state 2S1/2 |F=2, m_f=0⟩ and then a second photon pair resonantly drives to 2S1/2 |F=2, m_f=±1⟩. Co-propagating Raman fields impart only a spin flip whereas non-co-propagating fields transfer two photon recoil momentum to the atoms, thus entangling the internal spin with the external motion of the atoms. For site dependent control, we plan to use the high AC Stark shifts produced by the high intensity pulses.

Q1.0067 Control of ground state quantum beats in Cavity QED1, PABLO BARBERIS-BLOSTEIN, Universidad Nacional Autonoma de Mexico, HOWARD CARMICHAIL, University of Auckland, LUIS OROZCO, ANDRES SIMMARUSTI, PATTERSON BURKLEY, KULIN SIMONE, University of Maryland — Ground state quantum beats observed in the second order intensity correlation from a continuously driven atomic ensemble inside a two mode optical cavity are subject to decoherence. While driving the cavity with light of linear polarization (π transitions) the second order autocorrelation function is measured in the undriven mode (orthogonal polarization): a first photon detection prepares a superposition of atomic ground-state Zeeman sublevels and the second measures the cavity ground state beats. Between these two detections, the atoms can become excited and return to the ground state, emitting a photon back into the driven cavity mode or into modes other than the cavity modes. Depending on the drive strength this process can happen several times. Each time there is a relative phase advance between the Zeeman sublevels. It is possible to monitor this process by measurements on the driven mode. Here we propose a scheme to manipulate the loss of amplitude of the beats (decoherence) and the beat frequency shift, by controlling the driving field and postselecting on the basis of information gathered through measurement of the cavity modes.

1Work supported by CONACYT, NSF and the Marsden Fund of the RSNZ.

Q1.000686 Portable Gravimeter, ANDREW CHEW, DSO National Laboratories, MARAL SAHELGOZIN, J.S. RAJ, NANYANG TECHNOL. U., CHEN, JOSHUA WEINER, KEVIN COX, JILA, Dept. of Physics, University of Colorado — We have realized a cold-atom Raman laser operating deep into the bad-cavity (or superradiant) regime, where the atomic linewidth is much narrower than the cavity linewidth. Here we present our studies on the stability of this active oscillator to external perturbations. We report on the robustness of such an oscillator when implemented in an atomic system with extra degrees of freedom. The present results show that the coherence evolution of a single electronic spin associated with a Nitrogen Vacancy (NV) center in diamond can be coupled to the motion of a magnetized mechanical resonator. Specifically we use coherent manipulation of the spin to sense the driven and Brownian motion of the resonator under ambient conditions at a precision of 5 picometers. We discuss potential future applications of this technique including the detection of the zero-point fluctuations of a mechanical resonator, the realization of strong spin-phonon coupling at a single quantum level, and the implementation of quantum spin transducers.

Q1.00069 Coherent detection of mechanical motion with a single spin qubit, SHIMON KOLKOWITZ, QUINN UNTERREITMEIER, Harvard University, ANIA JAYICH, UC Santa Barbara, STEVEN BENNETT, Harvard University, PETER RABL, Institute for Quantum Optics and Quantum Information of the Austrian Academy of Science, JACK HARRIS, Yale University, MIKHAIL LUKIN, Harvard University — Mechanical systems can be influenced by a wide variety of extremely small forces, ranging from gravitational to optical, electrical, and magnetic. When mechanical resonators are scaled down to nanometer-scale dimensions, these forces can be harnessed to enable coupling to individual quantum systems. We present results showing that the coherent evolution of a single electronic spin associated with a Nitrogen Vacancy (NV) center in diamond can be coupled to the motion of a magnetized mechanical resonator. Specifically we use coherent manipulation of the spin to sense the driven and Brownian motion of the resonator under ambient conditions at a precision of 5 picometers. We discuss potential future applications of this technique including the detection of the zero-point fluctuations of a mechanical resonator, the realization of strong spin-phonon coupling at a single quantum level, and the implementation of quantum spin transducers.

Q1.00070 Probing individual environmental nuclear spins coupled to electronic spin defects with dynamical decoupling pulse sequences, QUINN UNTERREITMEIER, SHIMON KOLKOWITZ, STEVEN BENNETT, MIKHAIL LUKIN, Harvard University — Solid-state spin qubits are promising candidates for quantum computation and quantum communication applications, for which long coherence times are a prerequisite. In the case of single Nitrogen-Vacancy (NV) centers, the coherence times are often limited by interactions with the surrounding nuclear environment. In this poster we present recent experimental results demonstrating the detection of individual nuclear spins weakly coupled to single electronic spin defects beyond the “T2-star” limit using dynamical decoupling pulse sequences. We take advantage of the coherent nature of the hyperfine interaction to probe the nuclear environment of individual NV centers, and identify the nearby nuclear spins and determine their coupling strengths and relative positions to the NV. We observe coupling strengths ranging from 2 MHz down to 46 kHz, well below the limit imposed by “T2-star,” and observe multiple nuclei coupled to a single NV. We discuss potential applications of this technique in magnetometry and quantum information science.

Q1.00071 Dynamics and Stability of a Superradiant Laser1, JAMES THOMPSON, JUSTIN BOHNET, ZILONG CHEN, JOSHUA WEINER, KEVIN COX, JILA, Dept. of Physics, University of Colorado — We have realized a cold-atom Raman laser operating deep into the bad-cavity (or superradiant) regime, where the atomic linewidth is much narrower than the cavity linewidth. Here we present our studies on the stability of this active oscillator to external perturbations. We report on the robustness of such an oscillator when implemented in an atomic system with extra degrees of freedom beyond the simple three level model of recent theoretical proposals.

1We acknowledge support from ARO, NSF PFC and NIST.

Q1.00072 Towards a Portable Gravimeter, ANDREW CHEW, DSO National Laboratories, MARAL SAHELGOZIN, J.S. RAJ, VELLÆRE WINFRIED, LI YUAN LEY, MINGLI YONG, Nanyang Technological University, YUAN LIANG LIM, DSO National Laboratories, RAINER DUMKE, Nanyang Technological University — In recent years, there has been increased interest in the use of atom interferometers to measure gravity with high precision and accuracy. Such a gravimeter can be used to measure fundamental constants such as Newton's G and in practical applications such as geodesy and prospecting. Most atom gravimeters are designed for operation in the laboratory and not for transportation to various different environments. We present the preliminary results of our portable atom gravimeter. Our gravimeter employs two different atomic species, namely Rb-87 and Cs-133. The use of two different species of atoms allows us increase the output bandwidth as we can make nearly simultaneous measurements of two different atomic species. This portable gravimeter will thus allow us to transport the gravimeter to a variety of environments and allow us to make measurements of gravity in situ.

Q1.00073 Atomic Gravitational Wave Interferometric Sensors (AGIS) in Space1, ALEX SUGARBAKER, JASON HOGAN, DAVID JOHNSON, SUSANNAH DICKERSON, TIM KOVACHY, SHENG-WEI CHIOW, MARK KASEVICH, Stanford University — Atom interferometers have the potential to make sensitive gravitational wave detectors, which would reinforce our fundamental understanding of gravity and provide a new means of observing the universe. We focus here on the AGIS-LEO proposal [1]. Gravitational waves can be observed by comparing a pair of atom interferometers separated over an extended baseline. The mission would offer a strain sensitivity that would provide access to a rich scientific region with substantial discovery potential. This band is not currently addressed with the LIGO or LISA instruments. We analyze systematic backgrounds that are relevant to the mission and discuss how they can be mitigated at the required levels. Some of these effects do not appear to have been considered previously in the context of atom interferometry, and we therefore expect that our analysis will be broadly relevant to atom interferometric precision measurements. Many of the techniques relevant to an AGIS mission can be investigated in the Stanford 10-m drop tower.


2AS acknowledges support from the NSF GRFP, a DoD NDSEG Fellowship, and a Stanford Graduate Fellowship.
We investigate a weak signal pulse propagation in a SPDC in parallel with an unmodulated linearly polarized probe beam. As a result of nonlinear interaction with atoms modulated probe beams are generated. The CHA, HEUNG-ROYUL NOH, Chonnam National University, SANG EON PARK, KRISS, JONG-DAE PARK, CHANG-HO CHO, Paichai University — We present using strong interactions of single atoms and photons. Here, due to its proximity to the surface of the resonator, an atom experiences both strong 1-photon and surface interactions [1]. To advance beyond transient observations [1], we are currently working to trap single atoms within the evanescent field of a microtoroidal resonator using a single tapered fiber to provide both optical coupling and a dipole trap for the atoms [2-4]. Our goal is to realize a flexible experimental platform for investigations of small quantum networks using strong interactions of single atoms and photons.

We present a hybrid platform for quantum information processing and quantum simulations that is based on ultracold atom-ion systems, Diego Valente, Robin Côté, University of Connecticut — We present a hybrid platform for quantum information processing and quantum simulations that is based on ultracold atom-ion systems, and seeks to combine the advantages of other platforms that are already well established experimentally. By combining together the long coherence times of neutral atoms and the strong interactions of trapped ions we obtain unique properties that are not present in each of these subsystems when alone. We discuss the feasibility of these schemes for quantum information processing, as well as decoherence phenomena that will limit the effectiveness of this new platform for specific physical systems.
Characterizing single atom optical dipole traps


Characterizing single atom optical dipole traps, CHUNG-YU SHIH, Georgia Institute of Technology, MICHAEL GIBBONS, None, MICHAEL CHAPMAN, Georgia Institute of Technology — Trapping and manipulating individual neutral atoms in far off-resonant traps (FORTs) is a promising approach for quantum information processing. It is important to characterize the trapping environment of the atom and the atomic level shifts due to the trapping fields. Using non-destructive measurement techniques, we have measured the level dependent AC Stark shifts, trap frequencies, and temperature of single rubidium atoms confined in optical dipole traps.

supported by IARPA, Sandia, NSA, ONR, and the NIST Quantum Information Program

Towards a field-free junction for a network of radio-frequency surface electrode ion traps, R. JÖRDENS, U. WARRING, National Institute of Standards and Technology, USA, R. SCHMIED, University of Basel, Switzerland, D.L. MOEHRING, M.G. BLAIN, Sandia National Laboratories, USA, D. LEIBFRIED, D.J. WINELAND, National Institute of Standards and Technology, USA — Intersections between transport guides in a network of RF ion traps are a key ingredient to many implementations of scalable quantum information processing with trapped ions. Several junction architectures have been demonstrated so far, limited by varying radial secular frequencies. We report on the design and progress in implementing a field-free junction that employs switchable RF electrodes. An essentially RF-field-free pseudopotential guide between any two legs of the junction can be established by applying RF potential to a suitable pair of electrodes. The transport channel’s height above the electrodes, its depth and radial curvature are constant to within 15%.

Entanglement of cold molecules using strong optical pulses, FELIPE HERRERA, ROMAN V. KREMS, University of British Columbia — We show that a strong off-resonant optical pulse can be used to create entanglement in an ensemble of polar molecules. The laser field modifies the rotational structure of molecules, enhancing the effect of the dipole-dipole interaction between molecules. This generated entanglement between molecules in different rotational states after the pulse is over. The degree of entanglement can be controlled by shaping the intensity and duration of the pulse. We show that a single nanosecond pulse can be used to produce an entangled state of molecules separated by several hundreds of nanometers, and that a sequence of pulses generate entanglement between molecules separated by tens of micrometers. We describe the possibility of using molecules trapped on an optical lattice to test Bell’s inequalities by measuring orientation and alignment correlations. We also analyze the main sources of decoherence in the system and estimate the efficiency of two-qubit quantum gates for universal quantum computation with trapped polar molecules. Reference: F. Herrera, Ph.D. thesis, University of British Columbia, 2012.

Unforgeable Noise-Tolerant Quantum Tokens, NORMAN YAO, Harvard University, FERNANDO PASTAWSKI, Max Planck Institute for Quantum Optics, LIANG JIANG, IQI, California Institute of Technology, MIKHAIL LUKIN, Harvard University, IGNACIO CIRAC, Max Planck Institute for Quantum Optics — The realization of devices which harness the laws of quantum mechanics represents an exciting challenge at the interface of modern technology and fundamental science. An exemplary paragon of the power of such quantum primitives is the concept of “quantum money.”

A dishonest holder of a quantum bank-note will invariably fail in any forging attempts; indeed, under assumptions of ideal measurements and decoherence-free memories such security is guaranteed by the no-cloning theorem. In any practical situation, however, noise, decoherence and operational imperfections abound. Thus, the development of secure “quantum money”-type primitives capable of tolerating realistic infidelities is of both practical and fundamental importance. Here, we propose a novel class of such protocols and demonstrate their tolerance to noise; moreover, we prove their rigorous security by determining tight fidelity thresholds. Our proposed protocols require only the ability to prepare, store and measure single qubit quantum memories, making their experimental realization accessible with current technologies.

Advanced ion trap structures with integrated tools for qubit manipulation, J.D. STERK, F. BENITO, C.R. CLARK, R. HALTLI, C. HIGHESTRETE, C.D. NORDQUIST, S. SCOTT, J.E. STEVENS, B.P. TABAKOV, C.P. TIGGES, D.L. MOEHRING, D. STICK, M.G. BLAIN, Sandia National Laboratories, Albuquerque NM 87123 — We survey the ion trap fabrication technologies available at Sandia National Laboratories. These include four metal layers, precision backside etching, and low profile wirebonds. We demonstrate loading of ions in a variety of ion traps that utilize these technologies. Additionally, we present progress towards integration of on-board filtering with trench capacitors, photon collection via an optical cavity, and integrated microwave electrodes for localized hyperfine qubit control and magnetic field gradient quantum gates.

This work was supported by Sandia’s Laboratory Directed Research and Development (LDRD) Program and the Intelligence Advanced Research Projects Activity (IARPA). Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the US Department of Energy’s National Nuclear Security Administration under contract DE-AC04-94AL85000.

New approach for super-resolution imaging of NV-nanodiamonds, KEICHI ARAI, MIT, DAVID LE SAGE, NIR BAR-GILL, CHINMAY BELTHANGADY, DAVID GLENN, Harvard-Smithsonian, MY LINH PHAM, Harvard University, HUI-LIANG ZHANG, RONALD WALSWORTH, Harvard-Smithsonian — We describe a new approach for super-resolution imaging of nanodiamonds (NDs) containing NV centers. The random orientation of NDs in a static magnetic field allow each ND to be distinguished by the NV ESR Zeeman shift and spin-state-dependent fluorescence rate. We exploit this behavior as a photo-switch such that adjacent NDs emit fluorescence sequentially in time. Post-analysis of a series of images at each ESR resonance frequency can localize individual NDs with sub-wavelength resolution. This technique has the advantage of being compatible with CCD-based wide-field microscopy, and involves significantly less laser intensity and experimental complexity than STED-based approaches.

Cold Atoms, Molecules, and Plasmas III
Q1.00090 A Quantum Optics Toolbox for Polyatomic Molecules, MARTIN ZEPPENFELD, BARBARA G.U. ENGELRT, ROSA GLOECKNER, ALEXANDER PREHN, GERHARD REMPE, MPI for Quantum Optics — We present a combination of techniques to manipulate the external and internal degrees of freedom of polyatomic molecules. A novel microstructured electric trap provides ideal motional control for polar molecules, generating a box-like potential with tuneable homogeneous electric fields over a large fraction of the trap volume and high trapping fields only near the trap boundary. The combination with radiation fields to manipulate the internal degrees of freedom allows full control of the molecules. Specifically, microwave and RF fields couple rotational states. Vibrational excitation via an infrared laser provides a dissipative spontaneous decay. The homogeneous fields inside the trap allow individual states to be selectively addressed. As first applications, we have realized adiabatic cooling and opto-electrical cooling. Further improvements will allow fundamental experiments with a wide range of polyatomic molecules at ultracold temperatures.

3Ibid.
4Zeppenfeld, op. sit.

Q1.00091 Rydberg atoms in a linear magnetic atom guide1, 2, MALLORY TRAXLER, RACHEL SAPIRO, University of Michigan, CORNELIUS HEMPEL, Institute for Quantum Optics and Quantum Information, Innsbruck, KARL LUNDQUIST, ERIK POWER, GEORG RAITHEL, University of Michigan — We study the trapping and guiding of Rydberg atoms in a high-gradient two-wire magnetic atom guide. Samples of several hundred cold 59D/2 Rb Rydberg atoms are prepared at densities of order 2x10^11 cm^-3. The atoms are ionized after a variable delay time using a microwave pulse. The resulting ions are imaged onto a position-sensitive microchannel plate detector, and time-domain multi-scaler traces as well as gated CCD images of the ion signals are obtained. We observe guiding of Rydberg atoms over a period of 5 ms following excitation. There is a brief initial period during which about 7% of the Rydberg atoms undergo Penning ionization. The decay time of the guided atom signal is about five times that of the initial state lifetime. We attribute the increase in lifetime to an initial phase of l-changing collisions concurrent with the Penning ionization phase and also to thermal electric-dipole transitions. A Monte Carlo simulation reproduces most experimental observations and offers insight into the internal-state dynamics.

1This work has been supported by the Army Research Office (50396-PH). MT acknowledges support by a NDSEG fellowship.

Q1.00092 Few-body phenomena in ultracold cesium: More resonances, more bodies, and less dimensions, ALESSANDRO ZENESINI, BO HUANG, MARTIN BERNINGER, STEFAN BESLER, HANS-CHRISTOPH NAEGERL, FRANCESCA FERRALINO, Institut fuer Experimentalphysik and Zentrum fuer Quantenphysik, RUDOLF GRIMM, Institut fuer Experimentalphysik and Zentrum fuer Quantenphysik, Institut fuer Theoretische Physik und Quanteninformation — Efimov trimers represent the paradigm of universal few-body physics and they have been subject to manifold investigations [1]. An important quantity, both for theory and experiments, is the so-called three-body parameter, which fixes the positions of the Efimov resonances. Our measurements with ultracold cesium are consistent with a constant three-body parameter, even when different Feshbach resonances are involved for the tuning of the scattering length [2]. Furthermore, the wide tuning range allows us to explore a series of N-body states by observing four- and five-body recombination resonances [3]. In ongoing experiments, we investigate how few-body states behave when a dimensional confinement is applied, from a shallow three-dimensional trap to a quasi two-dimensional situation. Preliminary results show that the position of the Efimov resonance shows a pronounced shift to lower absolute values of the scattering length.


Q1.00093 Developing Density for Collisional Experiments with Ultracold Molecules Using a Magnetic Injector/Accumulator1, JOE VELASQUEZ. III, SRIDHAR LAHANKAR, PETER WALSTROM, MICHAEL DI ROSA, Los Alamos National Laboratory — A prerequisite to studying ultracold chemistry is achieving a sufficient collision frequency as facilitated by creating a high number density. In this poster we show that some of the basic concepts and components of particle injectors and accumulators used in accelerators can be exploited to generate dense ensembles of ultracold magnetic particles, including laser-cooled paramagnetic atoms and molecules. For example, particles will be injected in one magnetic state and stored in another, much like charge-exchange injection into accelerator storage rings, allowing the progressive growth in density. We test these concepts first with atoms in preparation for later work with molecules. Presently, the injector stage uses a magnetic field and optical pumping to switch the state and trajectory of laser-cooled atoms into the stored state and accumulator path. Particle tracking calculations, design, and experiments with the injection and accumulation of 7Li will be presented. Finally, we will present our preliminary results in laser cooling of CaH and efforts to implement an injector/accumulator for these ultracold molecules.

1Supported by the LDRD program of Los Alamos National Laboratory

Q1.00094 Imaging spatial correlations of Rydberg excitations in cold atom clouds1, ANDREW SCHWARZKOPF, DAVID ANDERSON, GEORG RAITHEL, Univ. of Michigan — We measure correlations between excitation positions in cold Rydberg gases. We have previously observed2 Rydberg-blockade-induced structures in the Rydberg pair correlation function similar to those predicted in.3 Here, we study the effect of Coulomb repulsion after field ionization, which could possibly influence the pair correlation measurement. We have simulated the ion trajectories in our chamber and determined that Coulomb repulsion did not play a role in any of our previous experiments. However, with higher magnification we expect to observe this effect as well. In the experiment, we already have obtained a magnification increase by about a factor of two, and progress towards even higher magnification is still being made. We will report on our progress in imaging smaller structures in the pair correlation function, induced by Coulomb repulsion and possibly by adiabatic Rydberg crystal formation.4

1We gratefully acknowledge support from AFOSR and NSF.
Q1.00095 Beyond mean-field effects in Bloch Oscillations of cold atoms in an optical cavity. 
PRASANNA VENKATESH BALASUBRAMANIAN, DUNCAN O’DELL, McMaster University — In our earlier publication [1] we proposed using Bloch oscillations of cold atoms inside an Fabry-Perot resonator for sensitive measurements of force. The analysis in [1] was performed using a coherent mean-field description for the atoms and the light. In the current work we extend this description substantially by including the effects of fluctuations in both the atomic and light fields. This analysis is used to set realistic limits on the precision to which the force can be measured. We also make contact with the optomechanical description of the combined atom-cavity system which has proved so successful for describing recent pioneering experiments [2].


Q1.00096 Photon mediated transport and crystallization in optically driven Rydberg gases. 
JOHANNES OTTERBACH, Harvard University, Cambridge, MA, USA, ACHIM LAUER, DOMINIK MUTH, MICHAEL FLEISCHHAUER, TU Kaiserslautern, Kaiserslautern, Germany — We show that excitations in a gas of atoms driven to Rydberg states by near-resonant laser radiation in a two-photon coupling scheme experience a photon mediated transport. Thus even if the center-of-mass motion of the atoms can be neglected, this results in a kinetic Hamiltonian for the Rydberg excitations. The corresponding mass is identical to that of the dark-state polaritons of the optical coupling scheme. The kinetic energy competes with the Rydberg dipole-dipole interactions and can prevent the formation of quasi-crystal structures. Using DMRG simulations we calculate the Luttinger parameter for a one-dimensional gas of resonantly driven Rydberg atoms taking into account the photon mediated transport and derive conditions under which quasi-crystallization can be observed.

Q1.00097 Non-Zero Temperature analysis of a quasi2D dipolar gas. 
CHRISTOPHER TICKNOR, Los Alamos National Laboratory — We present non-zero Temperature analysis of a quasi2D dipolar gas. To do this, we use the Hartree Fock Bogoliubov (HFB) method within the Popov approximation. This formalism is a set of non-local equations containing the dipole-dipole interaction and the condensate and thermal correlation functions, which are solved self-consistently. We detail the numerical method used to implement the scheme. We present density profiles for a non-zero temperature dipolar gas in q2D, and compare these results with a gas with zero-range interactions. Additionally, we analyze the excitation spectrum.

Q1.00098 Synthetic partial waves in ultracold atomic collisions. 
ROSS WILLIAMS, LINDSAY LEBLANC, KARINA JIMÉNEZ-GARCÍA, MATTHEW BÉÉLÉR, ABIGAIL PERRY, BILL PHILLIPS, IAN SPIELMAN, Joint Quantum Institute, NIST and University of Maryland — Interactions between particles can be strongly modified by their environment. We describe an experimental technique for modifying interactions between ultracold atoms by screening the native interaction with light, significantly increasing the range of the interaction and allowing coupling of states of higher angular momentum. We study collisions between Bose-Einstein condensates dressed by counter-propagating Raman beams, where the eigenstates of the Raman-dressed system are spin-momentum superpositions. Collisions between bosons at the low temperatures associated with quantum degeneracy are usually well-described by a purely isotropic (s-wave) interaction. In contrast we observed effective higher order (beyond s-wave) partial wave interactions between colliding BECs in the ground Raman dressed state at collision velocities orders of magnitude below those traditionally required to surpass the s-wave scattering regime. Furthermore we investigate scattering in excited Raman-dressed states and observe collision-induced decay to lower energy Raman-dressed states which can be p-wave or d-wave in character.

Q1.00099 Towards a $^{87}$Rb BEC apparatus with reconfigurable arbitrary optical potentials and artificial gauge fields. 
ROBERT NIFFENEGGER, ABRAHAM OLSON, YONG P. CHEN, Purdue University — We have constructed an all-optical $^{87}$Rb BEC apparatus, which is currently creating condensates in a 1550nm cross beam optical dipole trap every 30s. We present experimental progress toward implementing reconfigurable arbitrary optical potentials and artificial gauge fields in our apparatus. Time-averaged, dynamically-reconfigurable, arbitrary-shaped optical potentials are generated using a dual-axis AOM controlled by a two-channel high-bandwidth arbitrary RF waveform generator. Using a blue-detuned 532nm laser, we have demonstrated various optical potential geometries such as a tilting wedge, checkerboard and elliptical barriers. Such arbitrary, reconfigurable optical potentials will be used to explore quantum phase transitions in superfluids. Our excellent optical access also allows the addition of Raman beams of various arrangements. Raman dressed states can be used to induce spin dependent artificial gauge fields for studying physics such as the spin Hall effect.

Q1.00100 Collective excitations in quasi-2D Condensates. 
LIN XIA, DANIEL LOBBER, ERIC CORNELL, JILA, National Institute of Standards and Technology and University of Colorado — In lower-dimensional gases, remarkable physical phenomena arise due to confinement effects, for example the Berezinskii-Kosterlitz-Thouless transition or the Tonks-Girardeau gas. In a quasi-2D condensate, the frequency of collective excitations are shifted because of 2D effects [1,2]. We report our latest results on the measurements of collective excitation frequencies in quasi-2D condensates. These frequencies are normalized by precise measurements of the trapping frequency.


Q1.00101 Quantum Degenerate Gases in an All-Optical Toroidal Trap. 
G. EDWARD MARTI, RYAN OLFF, SEAN LOURETTE, DAN STAMPER-KURN, UC Berkeley, Dept. of Physics — Quantum degenerate gases confined in a toroidal potential show persistent currents, azimuthal sound waves, and other transport phenomena related to coherent, unrestricted flow around the waveguide. Sound waves and vortex states in a ring can be used to for accurate, absolute rotation sensing. We report on our latest results on the status of our all-optical toroidal trap for Bose-condensed $^{87}$Rb. We discuss techniques to generate angular momentum and unusual spin structures as well as future prospects with spiner gases and quantum degenerate lithium.

Q1.00102 Three-fermion system with s-wave interactions under anisotropic harmonic confinement. 
SEYED Ebrahim GHARASHI, D. BLUME, Washington State University — We develop an efficient numerical approach to solve the Schrödinger equation for three fermions in two different spin states with zero-range s-wave interactions under cylindrical harmonic confinement. Our approach builds on the work done for isotropic confinement [1] and is applicable to traps with integer aspect ratio. We reproduce the known results for the aspect ratio of unity and analyze the energy spectrum when the aspect ratio is different from one. In the weakly-interacting regime our results agree with perturbative calculations. The eigenenergies are used to calculate the third-order virial coefficient as functions of the aspect ratio, temperature and s-wave scattering length.


We acknowledge support by the ARO.
Q1.00103 Hyperspherical explicitly correlated Gaussian approach for four-body systems with finite angular momentum$^1$. D. RAJKHIT, D. BLUME, Washington State University — It has been predicted that four-body systems with angular momentum $L = 1$ and parity $\pi = +1$ exhibit four-body resonances [1,2] and Efimov physics [3]. To treat these phenomena in the hyperspherical framework, we extend the work of von Stecher and Greene [4] to finite angular momenta. In particular, we employ explicitly correlated Gaussian basis functions with global vectors to solve the hyperangular Schrödinger equation for four-body systems with $L^z = 1^+$ and $1^−$ symmetry. We apply the approach to four-fermion systems with unequal masses.


$^1$We acknowledge support by the ARO.

Q1.00104 Quasi-one-dimensional scattering in a discrete model. MANUEL VALIENTE, KLAUS MOLMER, Department of Physics & Astronomy, Aarhus University — We present quasi-one-dimensional scattering of one and two particles with short-range interactions on a discrete lattice model in two dimensions. One of the directions is tightly confined by an arbitrary trapping potential. In the case of two-particle scattering, we will show that more than one confinement-induced resonance appear due to the non-separability of the center-of-mass and relative coordinates on the lattice, which is a necessary ingredient in any experimentally relevant situation.

Q1.00105 Spatially Selective Imaging in a Three-Dimensional Optical Lattice$^1$. CAROLYN MELDGIN, DAVID CHEN, BRIAN DEMARCO, University of Illinois at Urbana-Champaign — We have developed a technique to isolate atoms at the center of a three-dimensional optical lattice. A microwave-frequency magnetic field is used to transfer the central atoms into a hyperfine state that is selectively imaged. The center is spectroscopically resolved using hyperfine-state-sensitive AC Stark shifts effected by crossed laser beams. We discuss how this technique may be applied to compressibility measurements to aid in the determination of the three-dimensional disordered Bose-Hubbard phase diagram.

$^1$We acknowledge funding from the DARPA OLE Program and the NSF.

Q1.00106 Adiabatic loading and cooling of SU(N) alkaline earth atoms in optical lattices. SALVATORE R. MANNANA, JILA / University of Colorado at Boulder, LARS BONNES, Institute for theoretical physics, University of Innsbruck, Austria, KADEN R.A. HAZZARD, JILA / University of Colorado at Boulder, STEFAN WESSEL, Institute for theoretical solid state physics, RWTH Aachen University, Germany, ANA MARIA REY, JILA / University of Colorado at Boulder — We present thermodynamic properties of SU(N) alkaline earth atoms adiabatically loaded onto optical lattices. In particular, we compute the final temperatures obtained by such a procedure and identify an enhanced cooling effect when increasing N. The combination of high temperature series expansion and extensive numerical calculations (Quantum Monte Carlo and DMRG) allows us to characterize this effect over a wide range of initial temperatures and to identify the temperature regime in which the physics is governed by SU(N) superexchange interactions. We discuss implications for ongoing experiments.

Q1.00107 States of one and two atoms in a rotating ring lattice. OTIM ODONG, JUHA JAVANAINEN, U. of Connecticut — We study the states of one and two bosonic atoms in a rotating ring lattice using a Hubbard type model, including phases on the tunneling matrix elements that depend on the rotation speed. The combination of the topology of the ring and the twisting boundary conditions of the wave functions due to the rotation leads to a rich phenomenology and novel methods to control the atoms in the lattice. For instance, the physics qualitatively depends on the parity of the number of lattice sites, and one can tailor the preparation of both one-atom and lattice dimer states by varying the rotation speed.


$^1$This work is supported by the DoD NSSEFF program, by NSF Grant PHY-0652914, and by the Institute for Quantum Information and Matter.
$^2$Spin Device Research Center, Korea Institute of Science and Technology 39-1 Hawolgok-dong, Seongbuk-gu, Seoul, 136-791, Korea
$^3$Department of Physics and Astronomy, Northwestern University, 2145 Sheridan Rd., Evanston, IL 60208

Q1.00109 ABSTRACT WITHDRAWN —

Q1.00110 Progress towards a Fermi Gas Microscope. THOMAS GERSDORF, VINAY RAMASESH, TAKUMA INOUE, MELIH OKAN, DAVID REENS, JORDAN GOLDSTEIN, WASEEM BAHR, MARTIN ZWIERLEIN, Massachusetts Institute of Technology — Attractively interacting degenerate Fermi gases near a Feshbach resonance have been used to realize the BEC-BCS crossover, while repulsive gases in optical lattices are expected to shed light on the physics of high-temperature superconductors. Local probes of these atomic systems should reveal microscopic correlations in such strongly interacting systems that cannot be directly extracted from bulk measurements. With the advent of quantum gas microscopy, the potential of such local probes has been demonstrated in bosonic gases. We are developing an experimental apparatus that combines quantum gas microscopy techniques with ultracold fermions in optical lattices to simulate strongly-correlated electronic systems. Our apparatus is designed to create degenerate gases of fermionic lithium and potassium as well as bosonic sodium. The gases will be loaded into a single layer of an optical lattice and imaged with a sub-micron resolution optical system capable of resolving individual sites. Our system opens the door to microscopic studies of phases that appear in the Fermi-Hubbard model including fermionic Mott insulators, antiferromagnets and d-wave superfluids, as well as topological phases that arise in the presence of synthetic gauge fields.
Q1.00111 Dynamics of matter waves in tailored optical and atomic lattices, JEREMY REEVES, BRYCE GADWAY, LUDWIG KRINNER, DANIEL PERTOT, MATTHIAS VOGT, DOMINIK SCHNEEBLE, Department of Physics and Astronomy, Stony Brook University — We report experimental results on the dynamics of atomic matter waves in temporally and spatially modulated lattices. In a first experiment, we investigated the effects of disorder on dynamical localization in a periodically-pulsed optical lattice in the framework of a kicked-rotor model. A second experiment explored the interplay between disorder and interactions in the damping of Bloch oscillations in a tilted disordered lattice. In a third experiment, we examined the diffraction of atomic matter waves from 1D “crystal” arrays of lattice-trapped atoms with respect to the temporal dynamics of matter-wave scattering. We also demonstrated the use of matter waves to detect forced antiferromagnetic ordering in an atomic spin-mixture.

1 Currently at Cavendish Laboratory, Univ. of Cambridge
2 Currently at Dept. Physics and Astronomy, Univ. of Wüzburg

Q1.00112 Orbital Excitation Blockade and Algorithmic Cooling of Strongly Correlated Quantum Gas, MING TAI, Harvard University, WASEEM BAKR, Massachusetts Institute of Technology, PHILIPP PREISS, RUICHAO MA, JONATHAN SIMON, MARKUS GREINER, Harvard University — Ultracold quantum gases in optical lattices provide a rich experimental toolbox for simulating the physics of condensed matter systems. Here we present a new blockade effect that employs the orbital dependence of the interaction between bosons in optical lattices to manipulate the onsite occupation in a strongly interacting quantum gas. We induce coherent orbital excitations by modulating the lattice depth and observe interaction-induced energy shifts in the modulation resonances. By sweeping the modulation frequency across several resonances we can deterministically remove atoms on individual sites based upon initial occupation. Using this number filtering approach, we have demonstrated algorithmic entropy removal from a high-temperature gas to the point that it Bose-condenses. This algorithmic cooling can be used to bring quantum gases to the pico-Kelvin regime required for observing strong correlations. Further applications of these methods include preparation of high fidelity quantum registers, imaging strongly-correlated quantum gases, and generation of entangled orbital states.

Q1.00113 ABSTRACT WITHDRAWN

Q1.00114 Single Mode Quantum Pumps using Wavepackets of Bose-Einstein Condensates, KUNAL DAS, PETER KOUFFALIS, ANDREW PYLE, Kutztown University of Pennsylvania — Quantum pumps generate transport by time-varying potentials but implementation in mesoscopic systems has remained elusive despite much interest. We apply a novel approach using counter-propagating wavepackets to study this quantum transport mechanism at the single mode level. This allows us to probe features not accessible with standard methods of mesoscopic physics: We examine the rich momentum distributions resulting from quantum pumps in different configurations, including a new one that operates like a “quantum paddlewheel.” We find that with dual periods, the momenta present a Floquet structure that interweaves both. Our simulations easily translate to experiments with Bose-Einstein Condensates in waveguides, being currently developed. One of the key advantages of our simulations, as well as related experiments, is that we can examine the effects of nonlinearity on quantum pumps. Despite the intrinsic spatial non-uniformity of wavepackets, we show that convergent results for nonlinear transport are obtained as packet widths are increased, provided that the peak density is kept constant. Our basic approach can be generalized to study most mesoscopic transport phenomena with ultracold atoms.

1 We acknowledge funding from NSF Grant No. PHY-0970012.
2 Currently at The College of William and Mary

Q1.00115 Reservoir induced criticality in 1D bosonic lattice systems, MATTHIAS MOOS, MICHAEL HOENING, MICHAEL FLEISCHHAUER, Department of Physics and Research Center OPTIMAS, University of Kaiserslautern, Germany — We discuss reservoir driven phase transitions to critical states in one-dimensional bosonic lattice systems subject to local dissipation. By coupling to local reservoirs fermionic and bosonic lattice systems can be driven to a steady state which shows criticality in the sense of a diverging correlation length. For free lattice bosons this criticality is generically associated with a dynamical instability of the system. To avoid this instability we introduce a nonlinearity by saturating the dissipative gain. We consider coupling of the lattice sites to common local reservoirs of different range and derive correlations as well as critical exponents of the induced quasi-phase transition in a mean-field approximation.

Q1.00116 Non-equilibrium physics of spinor quantum fluids, LAUREN AYCOCK, SRIVATSAN CHAKRAM, JOHN LOMBARD, MUKUND VENGALATORE, Cornell University — We are working towards a multispecies ultracold atom apparatus intended for studies of non-equilibrium physics of quantum degenerate spinor fluids. These studies rely on the ability to generate large spatially extended ensembles of ultracold gases. In addition, quantitative studies of the non-equilibrium dynamics require the development of techniques for time-resolved nondestructive images of these gases. We report on experimental progress towards both these goals. We complement these experimental efforts with theoretical studies of spinor gases in non-equilibrium scenarios. In particular, we present results on a dynamical Kosterlitz-Thouless transition in quasi-2D F=1 spinor gases.

Q1.00117 Construction of a Dye Laser for Use in Detecting Ultracold RbCa, HAYLEY WHITSON, ALEXANDRIA PARSAGIAN, MICHAELA KLEINERT, Willamette University — Ultracold heteronuclear molecules have seen increasing interest in the scientific community over the last few years. By controlling their ro-vibrational energy levels, ultracold molecules can be used for high precision spectroscopy, to study cold collisions with rich internal dynamics, as model systems for condensed matter physics, and as qubits in quantum information processing. We study the novel combination RbCa. In addition to a permanent electric dipole moment, it also possesses a permanent magnetic dipole moment. This makes it an ideal candidate to study strong long-range dipole-dipole interactions. A dye laser system will be used to ionize RbCa through resonantly enhanced multi-photon ionization (REMPI). We use a Nd:YAG pulsed laser to pump a dye solution in a quartz glass cell. The linewidth of the dye laser is narrowed through use of a diffraction grating in Littman-Metcalfe configuration. We have performed ab initio calculations to calculate the electronic energy levels of RbCa, and Franck-Condon factors to determine the best wavelength for REMPI. These data will be used to optimize further calculations of molecular energy levels.

1 This work has been supported by the National Science Foundation, the M.J. Murdock Charitable Trust, and Willamette University.
Q1.00118 Quasi-resonant transitions in ultracold collisions of hydrogen isotope dimers: zero-energy resonances in vibration space¹. B. H. YANG, P. C. STANCIL, University of Georgia, R. C. FORREY, Penn State University, S. FONSECA DOS SANTOS, N. BALAKRISHNAN, University of Nevada Las Vegas — The quasi-resonant rotation-rotation (QRRR) mechanism is studied theoretically in ultracold H₂, D₂, and HD self-collisions as a function of initial vibrational level ν. In the QRRR mechanism, the collision partners swap internal rotational excitation resulting in large cross sections and scattering lengths. The efficiency of the QRRR mechanism is a consequence of conservation of total system internal rotational angular momentum and near conservation of internal energy. Extending to high vibrational excitation, we find that the QRRR mechanism identified for H₂(ν = 1)→sH₂(ν = 0) by Quémener et al. [1] persists with scattering lengths, both real and imaginary, varying smoothly with ν. However, exceptions occur at select high values of ν where the scattering lengths are enhanced by orders of magnitude corresponding to the location of a zero-energy resonance in “vibration space.” Similar trends are seen for D₂ and HD self-collisions. If the QRRR mechanism operates in other ultracold dimer-dimer collision systems, then vibrational excitation may be used to “tune” the interaction strength similar to methods which use external fields or theoretical variation of the reduced mass.


Q1.00119 Using Feshbach-optimized photoassociation spectroscopy to determine potential energies for excited electronic states of dimers, JAMES DIZIKES, ERIC R.I. ABRAHAM, MICHAEL A. MORRISON, University of Oklahoma — Many experiments on ultracold (< 1 mK) gases use magnetic-field-induced Feshbach resonances to enhance photoassociation (PA) [1]. A magnetic field applied to a sample of trapped ultracold atoms induces a Feshbach scattering resonance that can increase the PA rate into bound excited molecular states. We are studying how to use Feshbach resonances in PA spectroscopy [2] to determine accurate excited-state Born-Oppenheimer potential energies. For ⁸⁵Rb₂ we present calculated resonance properties and energies for excited vibrational states that are inaccessible with conventional PA spectroscopy.


Q1.00120 Apparatus to image ultra-cold impurities in Bose-Einstein condensates¹, ANDREW CADOTTE, DAVID ANDERSON, RACHEL SATIRO, STEPHANIE MILLER, GÉORGI RAITHEL, University of Michigan — We present an experimental apparatus with enhanced ion imaging capabilities relative to our previously used set-ups. The apparatus will be employed to study interactions between ultra-cold impurities and Bose-Einstein condensates (BEC). Atoms will first be loaded into a primary Magneto-optical trap (MOT), which loads a secondary MOT, and then into a quadrupole-l offense-configuration (QUIC) trap, where a BEC is formed. Free ultra-cold ions will be made by photoionizing a few atoms. Stray electric fields are canceled by an electrode package surrounding the BEC-ion interaction region. The electric field of a sharp needle (tip diameter 125 microns) is used to generate highly magnified ion images. In our poster, we will discuss expected phenomena, which include quantum charge diffusion [R. Cote, E. Bodo, P. Zhang, and A. Dalgarno], mesoscopic molecular ion formation [R. Cote, V. Kharchenko, and M.D. Lukin, Massignan, C.J. Pethick, and H. Smith], ion self-trapping [R.M. Kalas and D. Blume], and ultra-cold plasma expansion (in the classical domain). We will show details of the experimental apparatus, which is in its final assembly stage.

¹We acknowledge support by the AFOSR and NSF.

Q1.00121 Progress towards creating and manipulating ultracold LiRb molecules¹, SOURAV DUTTA, ADEEL ALTAF, JOHN LORENZ, DANIEL S. ELLIOTT, YONG P. CHEN, Purdue University — We present our progress towards creating ultracold LiRb molecules from a dual species magneto-optical trap (MOT) of ⁷Li and ⁸⁵Rb. We suggest photoassociation (PA) pathways for efficient production of ultracold LiRb molecules based on our recent experimental work on spectroscopy of LiRb molecules (S. Dutta et al., Chem. Phys. Lett. 511, 7 (2011)). We discuss a scheme based on interference of optical transitions to create ultracold molecules in a superposition of rotational states, and their manipulation based on an optical-phase based coherent control technique. We describe our apparatus where ultracold LiRb molecules will be created using PA, oriented using optical-phase based coherent control, and then detected using multiphoton ionization. We also discuss the ability of our apparatus to image the orientation of such molecules.

¹This work is supported by the NSF grant number CCF0829918.

Q1.00122 Investigation of photoassociative transitions in NaCs detuned from the Cs D₁ line, PATRICK ZABAWA, AMY WAKIM, MAREK HARUZA, NICHOLAS BIGELOW, University of Rochester — We utilize photoassociation (PA) to form bound NaCs molecules in excited states detuned from the Cs ⁶²P₁/₂ dissociation asymptote. The PA structure consists primarily of levels belonging to the A¹Σ⁺, b¹Πₗ₀=0, b¹Π, and b¹Πₗ₂=2 electronic states. All of these but the A¹Σ⁺ electronic state dissociate to the Cs ⁶²P₁/₂ asymptote, indicating that free-bound excitation occurs even to deeply bound vibrational levels. We find that mixing between electronic states and an f-wave shape resonance enhances the free-bound transition moments. We infer properties of the scattering wave from the PA spectra, and investigate the populated ground states using photoionization and depletion spectroscopy.

Q1.00123 High power rapidly tunable system for laser cooling¹, EDUARDO GOMEZ, VICTOR MANUEL VALENZUELA JIMENEZ, LORENZO HERNANDEZ DIAZ, Institute of Physics, UASLP — Laser cooling experiments require light sources that can be rapidly tuned in frequency and power. Keeping as much power as possible increases the number of trapped atoms. We present a configuration that combines the capabilities of rapid frequency tuning with power amplification in a robust system. A double pass acousto-optic modulator (AOM) changes the frequency of the laser beam while keeping the alignment approximately constant. We decouple the modulation and amplification sections using an optical fiber and we keep the power out of the fiber constant by feedback on the amplitude modulation of the AOM. The tapered amplifier is in a double pass configuration and requires an input of only 1 mW to obtain 1 W out. A second modulator controls the intensity after the amplifier and generates additional beams that we use, for example, to do absorption imaging. We demonstrate the transfer of atoms to a dipole trap using the system.

¹Work supported by CONACYT.
Q1.00124 System for Trapping Cold Neutral Atoms Around an Optical Nanofiber1, J.A. GROVER, J.E. HOFFMAN, Z. KIM, J. LEE, I.D. SCHÖCH, K.D. VOIGT, A.K. WOOD, J.R. ANDERSON, M. HAFEZI, C.J. LOBB, L.A. OROZO, S.L. ROLSTON, J.M. TAYLOR, F.C. WELSTOOD, Joint Quantum Institute, Dept. of Physics, UMD and NIST, College Park, MD 20742, USA, S. RAVETS, Laboratoire Charles Fabry, Institut d’Optique, CNRS Univ Paris-Sud, Campus Polytechnique, RD 128, 91127 Palaiseau cedex, France — We have constructed a robust system for studying atom-light interactions in atomtronics and hybrid quantum information. We require the loading of atomic dipole traps formed on tapered optical nanofibers and other photonic structures from magneto-optical traps. A commercially available UHV manipulator allows for controlled translation of the structures into the chamber with the trap while reducing the turn-around time to obtain ultra-high vacuum. The translation and pump out protocols require care not to destroy or contaminate the fibers and other photonic structures. We can, for example, translate a 500 nm diameter, 2 cm length optical nanofiber to the center of a $^{87}$Rb cloud and load cold atoms into the evanescent field around the nanofiber. We also present experimental proposals to use the nanofiber trap as a microwave-to-optical photon transducer and as a part of a stable atomic memory in a hybrid quantum processor that combines atoms and circuit-QED.

1This work is supported by ARO MURI award W911NF0910406, Fulbright, and the NSF Physics Frontier Center at the JQI

Q1.00125 Analysis of a state-insensitive, compensated nanofiber trap1, C. LACROUTE, K.S. CHOP, A. GOBAN, D.J. ALTON, D. DING, N.P. STERN, H.J. KIMBLE, California Institute of Technology — Laser trapping and interfacing of laser-cooled atoms in optical fiber networks is an important capability for quantum information science. Following the work of [1] and [2], we propose a method of trapping single Cesium atoms with a two-color, state-insensitive evanescent wave near a dielectric nanofiber. The vector light shifts induced by the ellipticity of the forward-propagating wave can be canceled by a backward-propagating wave. By operating the trap at magic wavelengths, we remove the differential scalar light shift between ground and excited states, allowing for resonant driving of the optical D2 transition. Tensor shifts are inherent to the D2 excited state 6P1/2, but vanish for the D1 excited state 6P1/2. We show that the proposed scheme of [3] can be translated to the Cs D1 line, reducing further the excited state splitting. These properties will enable quantum-state engineering in optical traps near microscopic optical waveguides and resonators, including for implementations of quantum memories, coupling of single atoms and ensembles to optical and mechanical resonators, and studying 1-D spin chains. [1] Balykin et al, PRA, 70(1):014101, 2004. [2] Vetsch et al, PRL, 104(20):203603, 2010. [3] Lacroute et al, New J. Phys. (in press); arXiv:1110.5372v1.

1Research Supported by the DoD NSEFF program, by NSF Grant PHY-0652914, and by the Institute for Quantum Information and Matter.
2Now at Korea Institute of Science and Technology
3Now at Northwestern University

Q1.00126 Design of a Dual Anti-Helmholtz Magnet System for a Side-by-Side MOT, FRANK NARDUCCI, EO Sensors Division, Naval Air Station, Patuxent River Maryland, REBECCA PRAISER, CHARLES ADLER, Physics Department, St. Mary’s College of Maryland, St. Mary’s City, MD — The design of a cold-atom interferometeric gradient magnetometer [1] requires two side-by-side identical atom clouds separated by approximately 1 cm for noise reduction purposes. The first step in building this system is a side-by-side MOT to capture the atoms; however, the design of a coil system to provide two zero field crossings with high field gradients separated by a small distance with low power consumption can be challenging. These three requirements are not easy to satisfy simultaneously, but there is a large “state space” in which we can evolve different designs. In this poster we analyze the requirements for such a system and discuss our design consisting of coils with wires wrapped on a truncated cone; this type of design has been made possible by recent advances in 3D printers, and we will go over the issues involved in printing the coil supports, building the coils and comparison of our measurements with the magnetic field theory. We also discuss the possibility of optimizing coil design using state space searches like the Metropolis algorithm, and how these designs can be realized using 3D printing technology.


Q1.00127 Vacuum Pressure Measurements using a Magneto-Optical Trap1, T. ARPORNTHIP, C.A. SACKETT, University of Virginia, K.J. HUGHES, Triad Technology, Inc — We demonstrate that the loading dynamics of an alkali-atom magneto-optical trap (MOT) can be used as a reliable measure of vacuum pressure. This technique could be useful when a conventional pressure gauge is unavailable due to constraints on the vacuum system design. We find that for a MOT loading time $\tau$, the vacuum pressure can be estimated as $(2 \times 10^{-6}$ Torr$)/3$. This relation is accurate to within approximately a factor of two over wide variations in trap parameters, background gas composition, and trapped alkali species. At low pressures, the accuracy of the method is limited by losses from two-body elastic collisions within the trap. The loss rate from these collisions varies with the MOT parameters, but typically the method can extend into the $10^{-10}$ Torr range. We will present theoretical and experimental verification of the technique, based on both our own investigations and previous reports in the literature.

1Supported by the US Navy SBIR program.

Q1.00128 Coupling of ions to superconducting circuits, SOENKE MOELLER, NIKOS DANILIDIS, SEBASTIAN GERBER, HARTMUT HAEFFNER, UC Berkeley — We present experimental progress towards coupling the motion of ion strings to the resonant mode of a superconducting high-quality tank circuit. We consider such a coupling as the first step towards interfacing trapped ions with superconducting qubits. In our demonstration experiment, we aim to reduce the temperature of the resonant mode of the tank circuit by extracting energy from the circuit via laser cooling an ion string. One of the main experimental challenges is to construct a tank circuit with such a high quality factor $Q$ that the ion-resonator coupling exceeds the environment-resonator coupling. Currently, we achieve $Q = 27 000$ at a frequency of $\omega = 2\pi \cdot 1.2$ MHz. For this mode, the coupling time-scale to the environment is on the order of 50 Hz. We plan to use a trap with an ion-electrode distance on the order of 100 $\mu$m resulting in an ion-resonator coupling of 1 kHz. This coupling should reduce the electronic temperature of the resonant mode by two orders of magnitude as compared to the ambient temperature. The $Q$ of higher order resonant modes of our resonator reach the $10^6$ regime. We will discuss limitations of the observed $Q$ as well as improvements on the design such as trapping closer to the electrodes.

Q1.00129 A Quasi-Electrostatic Trap for Rubidium-87 atoms, DWIGHT WHITAKER, ZACK LASNER, ERIC DODDS, RYLAN GRADY, Pomona College — We will discuss our system used for trapping and cooling atoms with a single focused CO$_2$ laser beam. Atoms are transferred to this quasi-electrostatic trap (QUEST) from a compressed MOT (CMOT) where they are cooled through evaporation. We will describe how to optimize the CMOT to maximize the phase space density in the QUEST. We will also present a calculation that contrasts the dynamics of free evaporation in our single beam optical trap with evaporation in a truncated parabolic potential that describes a magnetic trap.

1Supported by the US Navy SBIR program.
Kinetic phenomena in electron transport in non-equilibrium plasmas sustained by radiofrequency electric and magnetic fields, SASA DJUKO, Institute of Physics, University of Belgrade, PO Box 68, Zemun 11080, Belgrade, Serbia, RON WHITE, ARC Centre for Antimatter-Matter Studies, School of Engineering and Physical Sciences, James Cook University, Townsville 4810, Australia, ZORAN PETROVIC, Institute of Physics, University of Belgrade, PO Box 68, Zemun 11080, Belgrade, Serbia — Future generation plasma discharge technologies require an accurate knowledge of the transport properties of charged particles in gases under the influence of electric and magnetic fields. In this work, the non-equilibrium transport of electrons in gases under the influence of radio-frequency electric (E) and magnetic (B) fields is studied via a unified time-dependent multi term solution of Boltzmann’s equation. We systematically investigate the explicit effects associated with the E and B fields including field to density ratios, field frequency to density ratio, field phases and field orientations. In particular, we highlight the duality of transport coefficients induced by the explicit and implicit effects of non-conservative collisional processes of attachment and ionization. A multitude of kinetic phenomena are observed that are generally unpredictable through the use of steady-state dc transport theory. Phenomena of significant note include the existence of transient negative diffusivity, time-resolved negative differential conductivity and anomalous anisotropic behavior of longitudinal and transverse diffusion coefficient along the E×B direction.

Electrostatic electron oscillations and damping in an ultracold plasma, KEVIN TWEDT, STEVEN ROLSTON, Joint Quantum Institute and Department of Physics, University of Maryland — We study various collective oscillations in ultracold plasmas by driving the oscillations with an applied rf field and measuring the current induced on a nearby electrode. Previously we made measurements of a zero-temperature edge-mode and confirmed the importance of the changing plasma neutrality in determining the resonant frequency. We present an equivalent circuit model for the plasma that is capable of reproducing the main features of the induced current signals that we observe. We attempt to use the model to measure the damping of the oscillation and how it changes with electron temperature. We also show results from driving cold plasma oscillations at an arbitrary angle to a uniform magnetic field, where we find a series of modes roughly consistent with upper hybrid oscillations and a series of modes at very low frequencies (<1 MHz) that are yet unidentified. This work is supported by the NSF.

Atomic Parity Non Conservation with Francium atoms in the FrPNC collaboration1, JIEHANG ZHANG, University of Maryland, SETH AUBIN, College of William and Mary, JOHN A. BEHR, TRIUMF, Canada, ROBERT COLLISTER, University of Manitoba, VICTOR V. FLAMBAUM, University of New South Wales, EDUARDO GÓMEZ, Universidad Autónoma de San Luis Potosí, GERALD GWINNER, University of Manitoba, DAN MELCONIAN, Texas A&M University, LUIS A. OROZCO, Joint Quantum Institute and University of Maryland, MATT R. PEARSON, TRIUMF, Canada, OLIVIER SHELBYA, McGill University, GENE D. SPROUSE, Stony Brook University, MICHAEL TANDECKI, University of Manitoba, ANNIKA VOSS, University of Manchester — The FrPNC collaboration is dedicated to the study of the nuclear weak interaction through measurements of Parity Violation in francium atoms. We are preparing to measure both the nuclear spin independent part of the interaction that results in the determination of the weak charge and the nuclear spin dependent part dominated by the anapole moment. The experiment has moved to TRIUMF in a room carefully shielded from RF noise. The Fr production at TRIUMF is on the isotope range of A=203-229 with yields up to 10^8 s^-1, giving us access to both the neutron deficient and rich sides. An ion optics system at the end of the beam line delivers the Fr ions to the neutralizer. The trapping side has been successfully tested with rubidium. The complete system delivers cold and trapped atomic Fr in a robust way to the science chamber where the measurements will take place.

Precise measurement of the 7P<sub>1/2</sub>-state hyperfine splittings and isotope shift in 203Tl and 205Tl, TARYN SIEGEL, GAMBHIR RANJIT, P.K. MAJUMDER, Williams College, Dept. of Physics — We have undertaken a series of high-precision atomic structure measurements in thallium to test ongoing ab initio atomic structure calculations of relevance to various symmetry violation tests in this particular element. Currently we are using a two-color, two-step spectroscopy scheme to measure of 7P<sub>1/2</sub> hyperfine structure and isotope shift using a heated quartz thallium vapor cell. Our group recently completed a similar experiment in indium[1]. Here, one laser, locked near the thallium 6F<sub>1/2</sub> → 7S<sub>1/2</sub> 378 nm transition excites both naturally-occurring isotopes to an intermediate state. A second laser at 1301 nm overlaps the UV beam within the thallium vapor cell in both a co-propagating and counter-propagating configuration. Analysis of subsequent IR absorption spectra as we scan across the 7S<sub>1/2</sub> → 1P<sub>1/2</sub> transition allows us to extract both hyperfine and isotope shift information for this excited state. Frequency modulation of the IR laser provides convenient in situ calibration method for the measured splittings. Our goal is to determine the thallium splittings with an accuracy of 0.1 MHz. Current results will be presented.

Shifts from distant neighboring levels in high-precision microwave spectroscopy of the n = 2 triplet helium fine structure, A. MARSMAN, M. HORBATSCH, E.A. HESSELS, York University — In previous work, the systematic shifts of a resonance due to quantum interference from a distant neighboring resonance were derived for a closed four-level system [1]. Here we consider n = 2 triplet helium fine structure transitions in the microwave regime which are of interest for more accurate determinations of the fine-structure constant. The shifts are evaluated for both the Ramsey method of separated oscillatory fields (SOF) and for single microwave pulses driving the system resonantly to the P<sub>3</sub> state. Despite being far off resonance, the P<sub>3</sub> state has a non-zero excitation probability and interference from the spontaneous radiation from from the two states causes a small shift in the line center for the measured interval.

Efficient detection of 2^3S<sub>1</sub>m = 0 states of atomic helium for improved precision measurements of helium 2^3P fine structure4, K. KATO, H. BEICA, E.B. DAVIDSON, D.W. FITZAKERLEY, M.C. GEORGE, C.H. STORRY, A.C. VUTHA, M. WEALE, E.A. HESSELS, York University — Thermal helium 2^3S metastable atoms can be detected with near unit efficiency by the electron ejected when they strike a stainless-steel surface. However, the 2^3S atoms and UV photons created in generating the metastable beam also produce ejected electrons. We remove the 2^3S atoms from our beam using 2.66-micron photons from a dc discharge lamp to drive the 2^3S atoms to the 2^1P state (which subsequently decays to the ground state). A Stern-Gerlach magnet removes the m=−1 and m=+1 2^3S atoms. Elastic collisions with argon gas scatters the 2^3S atoms out of the initial beam path, and thus away from the direction of the UV photons. The combination of these elements allows for high-efficiency detection of 2^3S<sub>1</sub> m=0 atoms with very low background due to singlet atoms, UV photons or 2^3S m±1 atoms, allowing for an improved signal-to-noise ratio for precision helium fine-structure measurements.

This work is supported by NSERC, CRC and CFI of Canada.


[4] This work is supported by NSERC, CRC and CFI of Canada.
Q1.00137 Nuclear spin-dependent parity violation in Cs and Fr1, MARIANNA SAFRONOVA, University of Delaware — The study of parity nonconservation (PNC) in cesium led to a first measurement of the nuclear anapole moment and allowed to place constraints on weak meson-nucleon couplings. These constraints were found to be in disagreement with the ones obtained from nuclear parity violating experiments. The discrepancy of the nuclear and atomic PNC studies motivated further investigation of Cs spin-dependent PNC amplitudes. The Fr experimental work is in progress at TRIUMF [Sheng et al., J. Phys. B 43, 074004 (2010)] and theoretical calculations are needed for future interpretation of the results.

1This work was supported by the NSF.

Q1.00138 High Resolution Rotational Spectroscopy of Zeeman & Hyperfine Effects in PbF & YbF1, RICHARD MAWHORTER, ALEX BAUM, BENJAMIN MURPHY, Pomona College, TREVOR SEARS, Brookhaven National Laboratory, N.E. SHAFER-RAY, University of Oklahoma, LUKAS ALPHEI, JENS-UWE GRABOW, Leibniz-Universitaet — Motivated by the ongoing search for the CP-violating electron electric dipole moment (e-EDM), rotational spectra of the radicals 207PbF and 208PbF were measured using a supersonic jet Fourier transform microwave spectrometer. Zeeman splitting was examined for 10 207PbF and 9 208PbF, J = 1/2 and J = 3/2 transitions using Helmholtz coils and magnetic fields up to ~4 Gauss. Transitions were observed with 0.5 kHz accuracy and 6 kHz pair resolution over a range of 2 – 26.5 GHz. The observation of these field dependent spectra allowed for the determination of the two body fixed g-factors, G0 and G1, of the electronic wave function. This is an important step in a possible future e-EDM experiment using either the 207PbF or 208PbF molecule, and our results compare reasonably well with recently calculated values. Observing the nuclear quadrupole hyperfine structure can also help characterize the critical electric field at the heavy atom nucleus in unstable but long-lived PbF as well as 173YbF. Energy level predictions based on our detailed studies of the 4 stable PbF isotopologues as well as previous optical and microwave spectra of YbF will facilitate forthcoming experimental studies and may also uncover nearby states of opposite parity which could also greatly benefit the eEDM search.

1TJS acknowledges support from DOE DE-AC02-98CH10886, NES from NSF-0855431, and JUG and LDA from DFG and Land Niedersachsen.

Q1.00139 Optical lattice clock: towards 10^{-17} uncertainty, NATHAN HINKLEY, University of Colorado, Department of Physics, JEFF SHERMAN, National Institute of Standards and Technology, NATHAN LEMKE, University of Colorado, Department of Physics, KYLE BELOY, LANL, SAED MIRZADEH, ORNL, ERIC HUDSON, UCLA — We describe a novel approach to directly measure the energy of the narrow, low-lying isomeric state in 229Th. Since nuclear transitions are far less sensitive to environmental conditions than atomic transitions, we argue that the 229Th optical nuclear transition may be driven inside a host crystal with a high transition Q. This technique might also allow for the construction of a solid-state optical frequency reference that surpasses the precision of current optical clocks, as well as improved limits on the variability of fundamental constants. Based on our new optical lattice clock fractional uncertainty = 3.4 x 10^{-16}. Principle contributions to this uncertainty were the blackbody Stark effect, atomic cold-collisions, and lattice ac-Stark shifts not canceled at the magic wavelength balancing scalar Stark shifts in clock states 1S0 and 3P0. We report significant advances in these areas, paving the way toward a total uncertainty near the 10^{-17} level. We have since measured the clock static polarizability, reducing the blackbody Stark shift uncertainty to 3 x 10^{-17}, now limited by thermal environment uncertainty. Ultracold collisions between fermionic 171Yb atoms are dominated by p-wave interactions between 1S0 and 3P0 states. Ramsey spectroscopy with ≈ 50% excitation cancels density-dependent shifts at the 5 x 10^{-18} level. We report progress measuring residual lattice ac-Stark shifts: polarizability away from the magic wavelength (x I, the lattice intensity), hyperpolarizability (x I^2) and multipole (M1-E2) effects (x sqrt(I)).

Q1.00140 Investigation of the optical transition of the 220Th nucleus in a solid-state environment1, WADE RELLERGERT, SCOTT SULLIVAN, UCLA, DAVID DEMILLE, Yale, RICHARD GRECO, MARKUS HEHLEN, JUSTIN TORG-ERSON, LANL, SAED MIRZADEH, ORNL, ERIC HUDSON, UCLA — We describe a novel approach to directly measure the energy of the narrow, low-lying isomeric state in 220Th. Since nuclear transitions are far less sensitive to environmental conditions than atomic transitions, we argue that the 220Th optical nuclear transition may be driven inside a host crystal with a high transition Q. This technique might also allow for the construction of a solid-state optical frequency reference that surpasses the precision of current optical clocks, as well as improved limits on the variability of fundamental constants. Based on our new optical lattice clock fractional uncertainty = 3 x 10^{-17}, now limited by thermal environment uncertainty. Ultracold collisions between fermionic 171Yb atoms are dominated by p-wave interactions between 1S0 and 3P0 states. Ramsey spectroscopy with ≈ 50% excitation cancels density-dependent shifts at the 5 x 10^{-18} level. We report progress measuring residual lattice ac-Stark shifts: polarizability away from the magic wavelength (x I, the lattice intensity), hyperpolarizability (x I^2) and multipole (M1-E2) effects (x sqrt(I)).

1This work is supported by the ARO, DARPA, and UCOP.

Q1.00141 A Cavity Enhanced 87Sr Optical Lattice Clock, TRAVIS NICHOLSON, JASON WILLIAMS, BENJAMIN BLOOM, SARA CAMPBELL, MICHAEL MARTIN, MATTHEW SWALLOWS, MICHAEL BISHOF, JUN YE, JILA and The University of Colorado — Optical lattice clocks based on alkaline earth atoms have the potential to outperform single atomic ion clocks (the best clocks to date) [1,2]. The promise of lattice clocks is due to their larger atom numbers, for quantum projection noise limited atomic clocks average down like 1/√N atoms. Our new 87Sr optical lattice clock utilizes a cavity enhanced 1D magic wavelength lattice to further improve our atom number [3]. The circulating power in our cavity allows us to operate at larger trap volumes than our previous retroreflected configuration while maintaining reasonable trap depths. These larger trap volumes enable us to transfer many more atoms into our lattice, improving our signal to noise. We will discuss our new cavity lattice clock system, and progress toward a comparison of two JILA lattice clocks will also be discussed. We will also touch on our goal of a 3D cavity enhanced lattice clock geometry.


Q1.00142 SPECIAL TOPICS (EXOTIC ATOMS AND MOLECULES; NONLINEAR DYNAMICS; NEW EXPERIMENTAL AND THEORETICAL METHODS; APPLICATIONS OF AMO SCIENCE) III —
Q1.00143 Measurement of electron beam polarization produced by photoemission from bulk GaAs using twisted light. NATHAN CLAYBURN, JOAN DREILING, University of Nebraska-Lincoln, JAMES MCCARTER, Thomas Jefferson National Accelerator Facility. DOMINIC POELKER, University of Nebraska-Lincoln — GaAs photocathodes produce spin polarized electron beams when illuminated with circularly polarized light with photon energy approximately equal to the bandgap energy [1, 2]. A typical polarization value obtained with bulk GaAs and conventional circularly polarized light is 35%. This study investigated the spin polarization of electron beams emitted from GaAs illuminated with “twisted light,” an expression that describes a beam of light having orbital angular momentum (OAM). In the experiment, 790nm laser light was focused to a near diffraction-limited spot size on the surface of the GaAs photocathode to determine if OAM might couple to valence band electron spin mediated by the GaAs lattice. Our polarization measurements using a compact retarding-field micro-Mott polarimeter [3] have established an upper bound on the polarization of the emitted electron beam of 2.5%. 


Q1.00144 Interaction of Wave Packets with an Oscillating Gaussian Barrier. TOMMY BYRD, MEGAN IVORY, A.J. PYLE, SETH AUBIN, JOHN DELOS, Dept. of Physics, College of William and Mary, Williamsburg, VA, KUNAL DAS, Dept. of Physics, Kutztown University, Kutztown, PA, KEVIN MITCHELL, Dept. of Physics, UC Merced, Merced, CA — We use classical, semiclassical, and quantum mechanics to examine a propagating wave packet that encounters an oscillating Gaussian potential barrier. The wave packet can be transmitted, reflected, or partially reflected and partially transmitted. The final wavefunction is constructed both semiclassically and quantum mechanically, and we examine the agreement between these two methods. It is believed that multiple oscillating Gaussian potential barriers may serve as a quantum pumping mechanism for ultracold atoms [1]. We have chosen to study first a simpler case, that of a single oscillating Gaussian barrier, with the intention of using these results for studying cases with multiple barriers.

Q1.00145 Proposal for unfolding single biomolecules in an ion trap. ERIK STREED, Griffith University, Australia — The functionality of biological molecules such as nucleic acids, proteins, and carbohydrates are driven by both their chemical composition and conformation. Ion trap mass spectrometry of large biomolecules is a well-established technique for primary sequence determination (composition) and is finding increasing use in investigating higher-order structure (conformation). Confining single isolated biomolecules in a ion trap provides a uniquely adaptable environment in which to investigate higher-order structure through manipulation of the surrounding solvent cage, temperature, and net charge at the single quantum level. We propose continuously observing these conformational changes in-trap though optical fluorescence techniques developed for in-vitro and in-vivo studies including Förster Resonance Energy Transfer (FRET) and super-resolution microscopy.

Q1.00146 A miniature mechanical shutter for atomic beams. STEPHANIE MILLER, DAVID ANDERSON, ANDREW CADOTTE, GEORG RAITHEL, University of Michigan — In many atomic physics experiments, atomic beams are generated for transport of atoms from a region of high (HV) to ultra-high vacuum (UHV). In such experiments, as well as those requiring a large number of atoms, it is desirable to load an atomic trap by a high flux source, such as a pyramidal magneto-optic trap (MOT) or Zeeman slower, without having the trap be affected by the atomic beam once loading is completed and subsequent experimental steps are initiated. We present here a mechanical shutter intended for this purpose in a BEC experiment. By implementing the shutter, we hope to block not only the beam, but other gases from entering the main chamber, resulting in improved evaporative cooling efficiency, which in turn will allow us to form BECs more quickly and easily. The shutter design discussed in detail here is unique in its small size (less than 5 mm in diameter, encompassing a magnet, steel rod, solenoid, and mu metal for magnetic shielding) and UHV compatibility. Performance parameters of the shuttering mechanism are also presented.

Q1.00147 Silica Nanowire Growth on Photonic Crystal Fiber by Pulsed Femtosecond Laser Deposition. NICHOLAS LANGELLIER, CHIH-HAO LI, GABOR FURESZ, ALEX GLENDAY, DAVID PHILLIPS, HUIJANG ZHANG, Harvard-Smithsonian, GUOQING NOAH CHANG, FRANZ KAERTNER, MIT, ANDREW SZENGTGYORGYI, RONALD WALSWORTH, Harvard-Smithsonian — We present a new method of nanowire fabrication using pulsed laser deposition. An 800 mW 1 GHz femtosecond Ti:Sapphire laser is guided into a polarization-maintaining photonic crystal fiber (PCF). The PCF, with a core tapered to 1.7 micron diameter, converts femtosecond laser pulses centered at 800 nm into green light with a spectrum down to 500 nm. The PCF is enclosed in a cylindrical tube with glass windows, sealed in a class 100 clean room with silicone-based RTV adhesive. The high power of each laser pulse in a silica-rich environment leads to growth of a silica nanowire at the output end of the PCF. SEM analysis shows that the pattern between the laser pulses is measured on a streak camera and analyzed through Fourier analysis. The PCF is contained within a shuttering mechanism, as described in [1], to block not only the beam, but other gases from entering the main chamber, resulting in improved evaporative cooling efficiency, which in turn will allow us to form BECs more quickly and easily. The shutter design discussed in detail here is unique in its small size (less than 5 mm in diameter, encompassing a magnet, steel rod, solenoid, and mu metal for magnetic shielding) and UHV compatibility. Performance parameters of the shuttering mechanism are also presented.

Q1.00148 Optical heterodyne analysis of picosecond laser pulses. STEVEN HOKE, JEFFREY JOHNSON, Arkansas State University — We present an optical heterodyne method to analyze laser pulses of picosecond duration using a frequency stabilized nanosecond laser. Optical heterodyning requires the linewidth of the nanosecond laser to be much smaller than the linewidth of the picosecond pulse being analyzed. This condition is easily achieved for seeded single-longitudinal-mode nanosecond lasers and seeded nanosecond OPOs. The timing of the two collinear lasers is adjusted such that the picosecond laser pulse arrives near the center of the nanosecond pulse, which fills the role normally performed by a CW laser. The beat pattern between the laser pulses is measured on a streak camera and analyzed through Fourier analysis.

Q1.00149 Sommerfeld’s Geometric View of Relativistic Vector Spaces: A Neglected Insight Revived. FELIX T. SMITH, Retired — In 1909 Sommerfeld showed that the structure of a space-time 4-vector (Δ, icΔ) implies that relativistic velocity vectors v occupy the space of geodesics on the 3-surface of a hypersphere of imaginary radius \( r_{\text{imag}} = ic \). This peculiar-seeming result in relativistic 4-space is comparable to the existence of a real sphere within a Euclidean 3-space, and Sommerfeld recognized it later (1931) as implying a spherical 3-space of negative curvature. This peculiar-seeming result in relativistic 4-space is comparable to the existence of a real sphere within a Euclidean 3-space, and Sommerfeld recognized it later (1931) as implying a spherical 3-space of negative curvature. These deductions are mathematically rigorous, and the implications for velocity vectors were accepted and used by Einstein (1921), but they have generally been ignored. The insights offered by Sommerfeld’s geometric view are complementary to what the prevailing tensor techniques can do. I show how they can be readily extended and applied, developing new insights and results, including (a) a hyperbolic polar representation of velocity 4-vectors, (b) the equivalent representation for position-time 4-vectors, and (c) a connection like that of a sphere with a tangent plane, joining relativistic 4-vectors and their nonrelativistic equivalents, providing quantitative connection formulas.

We gratefully acknowledge financial support from the United States Army Night Vision and Electronic Sensors Directorate under contract number W909MY-09-C-0001.
Q1.00150 Atomic Au and Pd Negative-Ion Catalysis of H\textsubscript{2}O, HDO, and D\textsubscript{2}O to Corresponding Peroxides\textsuperscript{1}  ARON TESFAMICHAEL, KELVIN SUGGS, ZINEB FELFLI, XIAO-QIAN WANG, ALFRED Z. MSEZANE, Clark Atlanta University — Fundamental ideas of muon-catalyzed fusion utilizing a negative muon, a deuteron and/or a triton, have been used in atomic Au and Pd negative ion-catalysis of H\textsubscript{2}O, HDO, and D\textsubscript{2}O, respectively, finding that Au\textsuperscript{−} is an excellent catalyst but the Pd\textsuperscript{−} ion has a higher catalytic effect, consistent with recent observations. The fundamental atomic mechanism responsible for the oxidation of water to peroxide has been attributed to the interplay between Regge resonances and Ramsauer-Townsend minima in low energy electron elastic total cross sections for Au and Pd atoms, along with their large electron affinities. Dispersion-corrected density-functional theory transition state calculations performed on atomic Au\textsuperscript{−} catalysis of water conversion to H\textsubscript{2}O\textsubscript{2}, have revealed that the formation of the Au\textsuperscript{2−} (H\textsubscript{2}O\textsubscript{2})\textsuperscript{2−} anion molecular complex in the transition state, provides the fundamental mechanism for breaking the hydrogen bonding strength in the catalysis of H\textsubscript{2}O\textsubscript{2} using the Au\textsuperscript{−} ion. Thus, the crucial link between low-energy electron elastic scattering resonances and low-energy chemical reaction dynamics has now been fully established.

\textsuperscript{1}Research supported by DOE Office of Science; AFOSR and Army Research Office

Q1.00151 Towards Probing Living Cell Function with NV Centers in Nanodiamonds, IGOR LOVCHINSKY, NICHOLAS CHISHOLM, ALEX SUSHKOV, PEGGY LO, AMY SUTTON, JACOB ROBINSON, NORMAN YAO, STEVEN BENNETT, HONGKUN PARK, MIKHAIL LUKIN, Harvard University — We report on recent progress in using nitrogen-vacancy (NV) centers in nanodiamonds as local probes of radical concentrations in living cells. Nanodiamonds are biologically inert, and NV centers within them are robust and can sense local magnetic fields with nanoscale resolution. The ability to monitor the local magnetic environment within the cell would provide a new tool to study organellar function during normal operation or in response to applied stimuli. In addition, radical concentrations have been linked to cancer, aging, and signaling between cells, thus proving to be of significant importance to the biological and medical sciences.

Q1.00152 Applications of Nuclear Spin Singlet States in Liquids and Solids, STEPHEN DEVIENCE, NUR BAR-GILL, DAVID LE SAGE, CHINMAY BELTHANGADY, LINH PHAM, MATTHEW ROSEN, RONALD WALSORTH, Harvard University — We explore applications of singlet states created from pairs of nuclear spins both in solutions and in solids. The singlet state is resistant to many decoherence mechanisms and can exhibit long coherence times. We show that measuring the decoherence of the singlet state allows us to detect intermolecular interactions, such as those due to binding between molecules. We also demonstrate that by manipulating the singlet states on target molecules we can extract spectral lines of the target that are overlapped by interfering peaks. Finally, we discuss the possibility of using singlet states in quantum-memory schemes in the solid-state.

Q1.00153 Depletion-based techniques for super-resolution imaging of NV-diamond, JEAN-CHRISTOPHE JASKULA, ALEXEI TRIFONOV, DAVID GLENN, RONALD WALSORTH, Harvard-Smithsonian — We discuss the development and application of depletion-based techniques for super-resolution imaging of NV centers in diamond: stimulated emission depletion (STED), metastable ground state depletion (GSD), and dark state depletion (DSD). NV centers in diamond do not bleach under optical excitation, are not biotoxic, and have long-lived electronic spin coherence and spin-state-dependent fluorescence. Thus NV-diamond has great potential as a fluorescent biomarker and as a magnetic biosensor.

Q1.00154 Altered States of Solid Xenon\textsuperscript{1}, MARK LIMES, ZAYD MA, BRIAN SAAM, University of Utah — Relaxation processes and structure in solid Xe were studied using hyperpolarization of \textsuperscript{129}Xe via spin-exchange from optically pumped Rb. In an applied field of 2T, we studied both longitudinal and transverse \textsuperscript{129}Xe relaxation; the former as a function of freezing conditions and the latter as a function of both freezing conditions and dilution of \textsuperscript{129}Xe and \textsuperscript{131}Xe atoms relative to spin-zero species. A flow-through polarizer \textsuperscript{[1]} is used to freeze and collect solid Xe (both \textsuperscript{129}Xe-enriched and naturally abundant), where we adjust the partial pressure of Xe in order to alter freezing conditions, which yield reproducible differences in spin-lattice relaxation times of greater than 10\%, apparently by varying the grain size. This is surprising because the mechanism is supposed to be a bulk Raman-phonon scattering process. In a separate convection cell \textsuperscript{[2]} experiment, we find that reducing the concentration of \textsuperscript{129}Xe and \textsuperscript{131}Xe narrows the NMR line shape, as expected. However, several anomalous features also arise, depending on the freezing rate. Dilute concentrations of spin-1/2 \textsuperscript{129}Xe range from 10\% to below 1\%.

\textsuperscript{[1]} Schrank, et al., PRA 80, 063424 (2009).
\textsuperscript{[2]} Su, et al., APL 85, 2429 (2004).

Q1.00155 UNDERGRADUATE RESEARCH —

Q1.00156 Impact of Decoherence on Internal State Cooling using Optical Frequency Combs, STEPHEN L. HORTON, SVETLANA A. MALINOVSKAYA, Stevens Institute of Technology — We discuss femtosecond Raman type techniques to control molecular vibrations, which can be implemented for internal state cooling from Feshbach states with the use of optical frequency combs. We analyzed the use of an optical frequency comb, with and without modulation, as a viable substitute to the STIRAP process. In our theoretical model we take into account molecular vibrations, which can be implemented for internal state cooling from Feshbach states with the use of optical frequency combs. We analyzed the spectra and the probability distributions inside the circular and sectorial billiard. As verification for the attractive case, as we increase the billiard radius our results approach the unbounded solutions. Finally we compare the classical probability distributions, obtained by assuming the probability as proportional to the time spent by the particle in each space interval, with the quantum ones.

Q1.00157 Quantum and classical analysis of circular and sectorial billiards with central harmonic potential, MANUEL JURADO-TARACENA, ALEXIS D. PLASCENCIA, JULIO C. GUTIERREZ-VEGA, Photonics and Mathematical Optics Group, Tecnológico de Monterrey, Monterrey, Mexico 64849 — We present the classical and quantum solutions to a particle confined in a circular sectorial billiard under a central harmonic potential, attractive and repulsive. The classical analysis is done by applying the Hamilton-Jacobi formalism; we derive the characteristic equations for periodic orbits, give expressions for the length of the trajectories in terms of elliptic integrals and study some geometrical constructions for the billiard. The quantum analysis leads to the study of the confluent hypergeometric function, from which we obtain the characteristic values for the energy spectra and the probability distributions inside the circular and sectorial billiard. As verification for the attractive case, as we increase the billiard radius our results approach the unbounded solutions. Finally we compare the classical probability distributions, obtained by assuming the probability as proportional to the time spent by the particle in each space interval, with the quantum ones.

Q1.00158 ABSTRACT WITHDRAWN —
Q1.00159 Quadratically coupled optomechanical systems . HAO SHI, MISHKATUL BHATTACHARYA, Rochester Institute of Technology — Typical optomechanical systems are composed of high finesse optical cavities that are coupled to mechanical oscillators, which are promising for classical as well as quantum applications. A well studied optomechanical configuration involves a optical cavity that is linearly coupled to the displacement of the mechanical oscillator. However, a quadratic coupling can also be realized between the cavity and the displacement of the mechanical oscillator using membranes, cold atoms, or microdisk-resonators. In the poster, I will describe our analysis of this new kind of coupling. The results include the exact solution of the corresponding Hamiltonian (in the absence of dissipation), a discussion of the spectrum and the eigenstates, and of the dynamics of the unitary evolution of the system. I will also discuss work planned for the future.

Q1.00160 Optical Production and Control of Photonic Structures . ALEX WALDROP, OLGA KOCHAROVSKAYA, Texas A&M University — Coherent control of the refractive index with vanishing absorption in multilevel systems and its applications were a subject of intense recent experimental and theoretical research [1-3]. We study the new possibility to use the coherent control of refractive index for optical production and control of photonic structures, such as distributed Bragg reflectors (DBR), holey fibers, photonic band gaps, and photonic crystals. We consider the construction of photonic structures in resonant homogeneous atomic media through the illumination laser field standing waves. Using sharp variation of refractive index, we can make the detuning from resonance spatially dependent and eliminate a resonant absorption on this detuning. This can be realized in three-level atoms in nearly degenerate ladder configuration with a populated intermediate level which position in space is modulated by an external control standing wave of a laser field via ac-Stark effect. We analyze the optimal geometry for realization of the proposed method and its possible implementation in rare-earth doped crystals with excited state absorption.

Q1.00161 Investigation of alkali-wall interactions in antirelaxation-coated vapor cells . R. ZOU, B. PATTON, T.J. SANTOS, N. BADDOUR, Department of Physics, University of California, Berkeley, M. BALABAS, S.I. Vavilov State Optical Institute, St. Petersburg, Russia, D. BUDKER, Department of Physics, University of California, Berkeley; Nuclear Science Division, LBNL — In experiments which employ room-temperature alkali vapors, antirelaxation coatings can dramatically increase the relaxation times of alkali atoms within a vapor cell. These coatings are crucial in many atomic physics experiments, such as: atomic magnetometry, electromagnetically induced transparency, atomic clocks, quantum control and measurement, etc. It is observed that the coatings have initial strong interactions with the alkali vapor after they are prepared, including suppression of alkali-vapor density and modification of the spin relaxation times. Cell curing refers to the change in properties of the internal surfaces of the vapor cells. We aim to understand what is going on during the initial interaction in order to possibly improve the coatings. In this experiment, we investigate how the interaction changes with time, we measure the rubidium vapor density using D1 line while tracking the rubidium vapor diffusing in a long coated glass tube. Further investigations include the relation between light induced atomic desorption and cell curing.

Q1.00162 POST-DEADLINE ABSTRACTS 

Q1.00163 Collective state measurement of mesoscopic ensembles with single-atom resolution . HAO ZHANG, ROBERT MCCONNELL, Massachusetts Institute of Technology; SENIKA ČUK, University of Belgrade, QIAN LIN, MONIKA SCHLEIER-SMITH, IAN LEROUX, VLADAN VULETIC, Massachusetts Institute of Technology — For mesoscopic ensembles containing 100 or more atoms we measure the total atom number and the number of atoms in a specific hyperfine state with single-atom resolution. The measurement detects an atom-induced frequency shift of an optical cavity containing the ensemble. This work extends the range of cavity-based detection with single-atom resolution by more than an order of magnitude in atom number, and provides the readout capability necessary for Heisenberg-limited atom interferometry.

Q1.00164 Experimental Angular Resolved Luminescence Measurements of Eu Ions in MgF2 . ALDO SANTIAGO RAMIREZ DUVERGER, RAUL GARCIA LLAMAS, RAUL ACEVES TORRES, Universidad de Sonora — The angular emission from Eu2+ ions in a system Al(substrat)/ MgF2-Eu2+/Al is measured. The thickness of the MgF2-Eu2+ films were optimized to support two guided mode, one at 323 nm and other at 420nm, whose values correspond to the excitation and emission wavelength of the Eu2+ ions, respectively. The coupling of the incident light to the guided mode was obtained by appropriate selection of the thickness of the Al film. When the guided mode in the excitation wavelength is excited, more Eu2+ elements in the waveguide are excited and therefore more elements contribute to the emission. If also, a guided mode in the emission wavelength is excited, it produces in the emission band of Eu2+ an increment of it value. Therefore, the spatial distribution of emission light as a function of the angle of incidence is enhanced in resonant condition as compared with off-resonance condition due to the incident light travels along the guide more efficiently.

Q1.00165 Electron Microscopy of Quantum Gases . Giovanni Barontini, Vera Guarrera, RaLa Labouve, Felix Stubenrauch, Andreas Vogler, Herwig Ott, TU Kaiserslautern, AG ULTRAKALTE QUANTENGASE TEAM — The technique of scanning electron microscopy allows for the investigation of solid surfaces and structures with a spatial resolution of few nanometers. Extending the application of this tool to a cloud of ultracold atoms, we obtain a novel way to image and manipulate the gaseous target, characterized by high spatial and temporal resolutions and by single atom sensitivity. A focused electron beam is moved over the cloud and ionizes the atoms by electron impact ionization. The produced ions are accelerated towards the collecting plate and their time-of-flight distribution is measured. This measurement provides information about the velocity and the number of atoms in a specific hyperfine state.

Q1.00166 Electron Dynamics with a Mixed Moving/Fixed Frozen Gaussian Basis Set . SHUNGO MIYABE, TODD MARTINEZ, Department of Chemistry and The PULSE Institute, Stanford University, Stanford, CA 94305 and SLAC National Accelerator Laboratory, Menlo Park, CA — In this report we simulate the strong field ionization of He atom using frozen Gaussian functions and demonstrate the importance of accurate bound state wavefunction in such a calculation. We expand the time-dependent electronic wavefunction using both static atom-centered Gaussian basis functions and trajectory-guided Gaussian wavepackets. We show that the ground state can be accurately described with a small basis set and we further show that this leads to an improved description of time-dependent processes such as ionization in strong fields. Our method combines the advantages of moving Gaussian wavepackets in the context of strong field attosecond phenomena with the advantages of traditional quantum chemistry techniques for describing low lying electronic states. We have computed the single ionization yield of He atom following its interaction with a 12 fs, 805 nm pulse, and show that the combination of static and moving basis set gives a highly correlated picture of the ionization event. We also computed the potential energy curves of H2 to show that our method describes the nuclear-dependence of electronic structure very well. In this work, the nuclei are fixed. However, we show how it is possible to model electronic and nuclear dynamics on the same footing.
Q1.00167 Observation of local temporal correlations in trapped quantum gases . VER A GUERRERA, GIOVANNI BARONTINI, RALF LABOVIC, FELIX STUBENRAUCH, ANDREAS VOGLER, HERWIG OTT, Fachbereich Physik, Technische Universität Kaiserslautern, AG ULTRAKALTE QUANTENGASE TEAM — We measure the temporal pair correlation function of a 3-dimensional trapped gas of bosons above and below the critical temperature for Bose-Einstein condensation. The measurement is performed in situ using a local, time-resolved single-atom sensitive probing technique, clear antibunching signal as a consequence of interaction induced "fermionization." Our results promote temporal correlations as new observables to study the dynamical evolution of ultracold quantum gases.

Q1.00168 Hyperfine frequency shift and Zeeman relaxation in alkali vapor cells with anti-relaxation alkene coating1, ERIC CORSINI, University of California, Berkeley, MIKHAIL BALABAS, S. I. Vavilov State Optical Institute, St. Petersburg, Russia, TODOR KARAULANOV, University of California, Berkeley, DMITRY BUDKER, University of California, Berkeley and Nuc. Sc. Div. Ø LB LN — A recently identified alkene based anti-relaxation coating exhibit Zeeman relaxation times in excess of 60 s in alkali vapor cells (two orders of magnitude longer than in paraffin coated cells). The long relaxation times, motivate revisiting the long-standing question of what is the mechanism underlying wall-collision induced relaxation and renew interest in applications of alkali vapor cells to secondary frequency standards. We measure the Zeeman relaxation time, and the width and frequency shift of the clock transition.:$^{39}$Rb using a clock cavity in aluminum coated and paraffin coated alkali vapor cells. We find that the frequency shift is slightly larger than for paraffin coated cells. However we observe that the Zeeman relaxation rate appears to be a linear function of the hyperfine frequency shift, whereas a linear dependence was not observed in paraffin coated cells. To shed light on this result we propose a model describing different Zeeman relaxation mechanisms of alkene and alkane cell-wall coatings.


Q1.00169 Methods to Characterize Vapor Cell Performance for Nuclear Magnetic Resonance Applications, JAMES MIRIJANIAN, California Polytechnic State University - San Luis Obispo, MICHAEL LARSEN, Northrop Grumman - Navigation Systems Division — The Advanced Sensors Development team at Northrop Grumman, Navigation Systems Division is developing a Nuclear Magnetic Resonance Gyroscope (NMRG). Various methods to measure atomic spin lifetimes in vapor cells for predicting NMRG performance have been investigated. Certain methods show clear advantages over others by requiring reduced testing times and improving test data resolution. New modifications of methods were also developed to study and improve the precision and repeatability of test results. These methods help correlate vapor cell performance to cell filling and sealing methods for cell fabrication process improvement. The vapor cells produced in conjunction with these techniques have exhibited significant and consistent increases in both the noble gas spin lifetimes and the NMR signal strengths compared to previous cell fabrication processes, providing more precise insight into cell development techniques.

Q1.00170 Nuclear Magnetic Resonance Gyroscope, MICHAEL BULATOWICZ, PHILIP CLARK, ROBERT GRIFFITH, MICHAEL LARSEN, JAMES MIRIJANIAN, Northrop Grumman - Navigation Systems Division — The navigation grade micro Nuclear Magnetic Resonance Gyroscope (micro-NMRG) being developed by the Northrop Grumman Corporation is concluding the fourth and final phase of the DARPA Navigation Grade Integrated Micro Gyro (NGIMG) program. Traditional MEMS gyros utilize springs as an inherent part of the sensing mechanism, leading to bias and scale factor sensitivity to acceleration and vibration. As a result, they have not met performance expectations in real world environments and to date have been limited to tactical grade applications. The Nuclear Magnetic Resonance Gyroscope (NMRG) utilizes the fixed precession rate of a nuclear spin in a constant magnetic field as an inertial reference for determining rotation. The nuclear spin precession rate sensitivity to acceleration and vibration is negligible for most applications. Therefore, the application of new micro and batch fabrication methods to NMRG technology holds great promise for navigation grade performance in a low cost and compact gyro. This poster will describe the history, operational principles, and design basics of the NMRG including an overview of the NSD designs developed and demonstrated in the DARPA gyro development program. General performance results from phases 3 and 4 will also be presented.

Q1.00171 Electron Paramagnetic Resonance – Nuclear Magnetic Resonance Three Axis Vector Magnetometer, MICHAEL BULATOWICZ, PHILIP CLARK, ROBERT GRIFFITH, MICHAEL LARSEN, JAMES MIRIJANIAN, Northrop Grumman - Navigation Systems Division — The Northrop Grumman Corporation is leveraging the technology developed for the Nuclear Magnetic Resonance Gyroscope (NMRG) to build a combined Electron Paramagnetic Resonance – Nuclear Magnetic Resonance (EPR-NMR) magnetometer. The EPR-NMR approach provides a high bandwidth and high sensitivity simultaneous measurement of all three vector components of the magnetic field averaged over the small volume of the sensor’s one vapor cell. This poster will describe the history, operational principles, and design basics of the EPR-NMR magnetometer including an overview of the NSD designs developed and demonstrated to date. General performance results will also be presented.

Q1.00172 Alignment Effects in the Fully Quantum State Resolved Inelastic NO(X) + Rare Gas Collisions, BALAZS HORUNG, MARK BROUARD, HELEN CHADWICK, CHRIS J. EYLES, BETHAN NICHOLS, MICHAEL SCOTT, Department of Chemistry, University of Oxford, UK, JAVIER AOIZ, PABLO G. JAMBRINA, Departamento de Quimica Fisica, Universidad Complutense, Spain, MARCELLO DE MIRANDA, School of Chemistry, University of Leeds, UK, STEVEN STOLTE, Institute of Atomic and Molecular Physics, Jilin University China — The rotational alignment effects in the rotationally inelastic scattering of NO(X $^2$Π) with Ar and Kr have been investigated by means of quantum mechanical, quasi-classical trajectory, and Monte Carlo scattering calculations. It has been shown that the repulsive nature of the interaction potential at a collision energy of 65 meV is doublet resolved alignment moments are reported.

Q1.00173 Femtosecond time-resolved imaging of torsion in an axially chiral molecule , J.L. HANSEN, INANO, Aarhus University, 8000 Aarhus C, Denmark, C.B. MADSEN, Department of Physics, Kansas State University, 116 Cardwell Hall, Manhattan, KS, 66506, USA, L.B. MADSEN, Department of Physics and Astronomy, Aarhus University, 8000 Aarhus C, Denmark, H. STAPELFELDT, Department of Chemistry, Aarhus University, 8000 Aarhus C, Denmark — The use of laser pulses to control the transition from one enantiomer of a chiral molecule to its mirror form has been the subject of a large number of theoretical studies driven by the intriguing prospects of light-induced deraecemization, i.e. creation of enantiomeric excess. Here we provide new experimental insights to how the combination of long (nanosecond) and short (femtosecond) laser pulses can be used to induce torsion in an axially chiral biphenyl derivative, here 3,5-diuroco-3,5'-dibromo-4'-cyano-(benzophenyl. The long, elliptically polarized, laser pulse 3D aligns the molecule, and the, linearly polarized, short pulse initiates torsion on the stereogenic axis. The torsional motion is monitored directly by determining the dihedral angle using femtosecond time-resolved Coulomb explosion imaging. At shutter times (0-4 ps) torsion occurs with a period of 1.25 picoseconds and an amplitude of 3˚ in excellent agreement with theoretical calculations. At longer times torsion is blurred by delocalization of the molecular orientation due to overall rotation of the molecule consistent with our theoretical model. Furthermore, a new imaging analysis technique, relying on the correlation between the ejected ionic fragments, supports our interpretation of the experimental data.
Q1.00174 Orientation-dependent ionization yields from strong-field ionization of fixed-in-space linear and asymmetric top molecules. J.L. HANSEN, iNANO, Aarhus University, 8000 Aarhus C, Denmark, D. DIMITROVSKI, L.B. MADSEN, Department of Physics and Astronomy, Aarhus University, 8000 Aarhus C, Denmark. — The ionization step leading to single ionization in the multiphoton or tunnel ionization regime is a fundamental process which is thought to be well understood for atoms; however, for larger molecules much less is known. Of particular importance is the understanding of the dependence of the initial ionization step on the molecular orientation with respect to the external field. To fully test existing theories and to guide the way for new theory development, we here extend these experiments to larger and more complex molecular systems. Carbonyl sulphide (OCS), benzonitrile and naphthalene. In particular we investigate the yield of strong-field ionization, by a linearly polarized probe pulse, as a function of the relative orientation between the laser field and the molecule. This is achieved using standard laser alignment techniques to produce 1D or 3D aligned molecular ensembles before a femtosecond laser probe pulse singly ionizes the target molecules. For naphthalene and benzonitrile, the orientational dependence of the ionization yield agrees well with the calculated results, in particular, we observe that ionization is maximized when the probe laser is polarized along the most polarizable axis. For OCS the observation of the maximum ionization yield when the probe is perpendicular to the internuclear axis contrasts the theoretical results.

Q1.00175 Monte Carlo Ground State Energy for Trapped Boson Systems. ETHAN RUDD, N.P. MEHTA, None — Diffusion Monte Carlo (DMC) and Green’s Function Monte Carlo (GFMC) algorithms were implemented to obtain numerical approximations for the ground state energies of systems of bosons in a harmonic trap potential. Gaussian pairwise particle interactions of the form $V_{ij} = \left(1 + \frac{r_{ij}}{a_0^2}\right)^{2}$ were implemented in the DMC code. These results were verified for small values of $V_{ij}$ via a first-order perturbation theory approximation for which the N-particle matrix element evaluated to $\frac{\langle 0 | V_{ij} | 0 \rangle}{\langle 0 | a^2 | 0 \rangle}$. By obtaining the scattering length from the 2-body potential in the perturbative regime ($\frac{V_{ij}}{a_0^2} \ll 1$), ground state energy results were compared to modern renormalized models by P.R. Johnson et al., New J. Phys. 11, 093022 (2009).

Q1.00176 Seconds-scale Light Storage. LIN LI, YAROSLAV DUDIN, ALEX KUZMICH, Georgia Institute of Technology — We report on achieving ultra-long lifetimes for coherent light storage. An optically thick sample of $^{87}$Rb confined in a far-off-resonance optical lattice is used as the storage medium. Ground state differential Stark shift is compensated via “magic” magnetic field technique. The observed 1/e lifetime for storage and retrieval protocol employing the clock (0-0) transition is 5 s. After the storage protocol is augmented by a dynamic decoupling with a sequence of microwave pi-pulses, the 1/e lifetime for storage of coherent light is further increased, up to 16 s.

Q1.00177 Investigation of Transparent Silicon Carbide Properties for Atom Chips Sensors. L. HUET, Thales Research and Technology, Thales Underwater Systems, M. AMMAR, Thales Research and Technology, Ecole Normale Supérieure, E. MORVAN, N. SARAZIN, Thales III-V Lab, J.-P. POCHOLLE, Thales Research and Technology, J. REICHEL, Ecole Normale Supérieure, C. GUERLIN, S. SCHWARTZ, Thales Research and Technology — Atom chips are an efficient tool for trapping, cooling and manipulating cold atoms. This is in particular due to the fact that they can achieve strong magnetic field gradients near the chip surface, hence strong atomic confinement. However, this advantage typically comes at the price of reducing the optical access to the atoms, which are confined very close to the chip surface. Moreover, the maximum achievable confinement strongly depends on thermal management issues within the atom chip. We report in the following experimental investigations showing how these limits could be pushed further by using an atom chip made of a gold microcircuit deposited on a single-crystal Silicon Carbide (SiC) substrate. With a band gap energy value of about 3.2 eV at room temperature, the latter material is transparent at 780 nm, potentially restoring quasi full optical access to the atoms. Moreover, it combines a very high electrical resistivity (over 105 W.cm ) with a very high thermal conductivity (over 390 W.m-1.K-1), making it a good candidate for supporting wires with large currents without the need of any additional electrical insulation layer. We have demonstrated robust magneto-optical trapping (MOT) of about one million rubidium atoms through the SiC chip.

Q1.00178 Generation of Tunable, Coherent Terahertz Radiation Through Molecular Modulation. JOSHUA WEBER, DENIZ YAVUZ, University of Wisconsin-Madison — We introduce and numerically model an approach for generating coherent terahertz radiation. Our method is based on our experimental work with high frequency (10-100 THz) continuous-wave light modulation. We use continuous-wave stimulated Raman scattering inside a high-finesse cavity to modulate light at molecular frequencies. Our simulations demonstrate how this approach could be expanded to generate radiation outside of the optical range. An infrared mixing beam from a semiconductor diode laser could be frequency down-shifted by the molecular modulator in order to generate radiation in the terahertz region of the spectrum. The generated radiation would be easily tunable, as a tuning range of a few tens of nanometers in the diode laser would allow for generation of radiation spanning the entire terahertz region (1-10 THz). We explore the efficiency of this generation using numerical simulations with experimentally available parameters.

Thursday, June 7, 2012 5:30PM - 5:42PM –
Session R1 DAMOP Business Meeting Garden 3

5:30PM R1.00001 DAMOP Business Meeting –

Thursday, June 7, 2012 6:30PM - 9:30PM –
Session S1 Reception and Banquet Grand Ballroom BCD

6:30PM S1.00001 Reception and Banquet –

Friday, June 8, 2012 8:00AM - 10:00AM
Session T1 Invited Session: Rydberg Gases and Ultracold Plasmas Grand Ballroom BCD - Chair: Charles Adams, Durham University
8:00AM T1.00001 Ultracold Neutral Plasma Density Waves. THOMAS KILLIAN, Rice University — Ultracold neutral plasmas, which are created by photoionizing laser cooled atoms near the ionization threshold, have been extensively studied in order to probe strong Coulomb coupling effects, low-energy atomic processes, equilibration, and collective phenomena [1]. The experimental study of collective modes, however, has previously been limited to phenomena involving electrons. By spatially modulating the intensity pattern of the photoionizing laser, we are now able to create controlled density perturbations on the plasma, which enables study of ion collective behavior. Periodic modulation excites ion acoustic waves [2]. We have also created two distinct plasmas that stream into each other. In the hydrodynamic regime, the central gap between the two plasmas splits into two density “holes” that propagate away from the plasma center at the ion acoustic velocity. At lower densities and higher particle velocities, plasmas are less collisional, and we observe kinetic effects such as plasma streams penetrating each other, with a penetration depth that reflects the ion stopping power. This general technique for sculpting the density opens many new possibilities, such as investigation of non-linear phenomena, instabilities, and shock waves in the ultracold regime, and determination of the effects of strong coupling on dispersion relations. The low temperature, small size, plasma expansion, and strongly coupled nature of ultracold plasmas make these studies fundamentally interesting. They may also shed light on similar phenomena in high energy density, laser-produced plasmas that can be near the strongly coupled regime.


This work is supported by the U.S. National Science Foundation, the Department of Energy, and Keck Foundation. Collaborators: J. Castro and P. McQuillen

8:30AM T1.00002 Trilobites and other molecular animals: How Rydberg-electrons catch ground state atoms. TILMAN PFAU, Universitaet Stuttgart — We report on laser spectroscopy results obtained in a dense and frozen Rydberg gas. Novel molecular bonds resulting in ultralong-range Rydberg dimers were predicted [1] and dimers as well as trimers in different vibrational states were found [2]. Some of these states are predicted to be bound by quantum reflection. Lifetime measurements confirm this prediction. Coherent superposition between free and bound states have been investigated [3]. Recently we have also confirmed that in an electric field these homonuclear molecules develop a permanent dipole moment [4].


9:00AM T1.00003 How electron collisions shape an ultracold plasma. EDWARD GRANT, University of British Columbia — Excitation of diatomic nitric oxide in a supersonic molecular beam forms a Rydberg gas with a temperature less than 1 K in the moving frame. This system relaxes to a molecular ultracold plasma with properties very comparable to plasmas formed by Rydberg excitation or threshold photoionization of atoms in a MOT. While, both MOT and molecular beam plasmas expand on a microsecond timescale with velocities determined by the electron temperature and the mass of the positive ions, molecular beam plasmas appear to expand slower than MOT plasmas suggesting a state of strong coupling. This observation challenges the conventional understanding of these systems. The nitric oxide plasma differs from MOT plasmas in one very important fundamental respect. Molecular cations carry the positive charge, and when a diatomic NO+ ion recombines with an electron, it can dissociate to neutral atoms. The spatial distribution of ions and electrons in a quasi-neutral plasma determines the driving force for expansion. Dissociative recombination occurs fastest in the core of the plasma. This loss channel flattens the charged-particle density distribution in the centre. Model calculations show that this suppresses the expansion of the core, channeling the thermal energy of the electrons to flow instead to the hydrodynamic motion of the peripheral ions.

9:30AM T1.00004 Nonlocal light-matter interactions in cold Rydberg gases. THOMAS POHL, MPI for the Physics of Complex Systems, Dresden, Germany — By virtue of their exaggerated properties, cold Rydberg atoms are considered to be promising systems for exploring quantum phenomena on a few- and many-body level. In this talk we discuss different facets of the laser-driven excitation dynamics in ultracold Rydberg gases. The evolution of both the atoms as well as the applied light-field displays profound effects of the strong van der Waals interactions between Rydberg atoms. On the one hand, they gives rise to long-range and collective atomic interactions that induce nonlocal matter-wave dynamics and the formation of exotic quantum phases. On the other hand, this system provides a well-controllable nonlocal optical medium with enormous nonlinearities. We discuss the resulting nonlinear light propagation and possible applications to photonic quantum computation.

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Friday, June 8, 2012 8:00AM - 10:00AM —
Session T2 Novel Optical Lattices

8:00AM T2.00001 Creating, moving and merging Dirac points with a Fermi gas in a tunable honeycomb lattice. GREGOR JOTZU, Leticia Tarruell, Daniel Greif, Thomas Uehlinger, Tilman Esslinger, Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland — We report on the creation of Dirac points with adjustable properties in a tunable honeycomb optical lattice. Using momentum-resolved inter-band transitions, we observe a minimum band gap inside the Brillouin zone at the position of the Dirac points. We exploit the unique tunability of our lattice potential to adjust the effective mass of the Dirac fermions by breaking the inversion symmetry of the lattice. Moreover, changing the lattice anisotropy allows us to move the position of the Dirac points inside the Brillouin zone. When increasing the anisotropy beyond a critical limit, the two Dirac points merge and annihilate each other. We map out this topological transition in lattice parameter space and find a kagome phase between incommensurate states. Our results pave the way to model materials where Berry phases and the topology of the band structure play a crucial role. Furthermore, they provide the possibility to explore many-body phases resulting from the interplay of complex lattice geometries with interactions.
8:12AM T2.00002 Trapping of Ultracold Atoms in a 10 \( \mu \text{m} \)-Period Permanent Magnetic Lattice

RUSSELL McLEAN, SMITHA JOSE, PRINCE SURENDRA, LESZEK KRZEMIEN, SHANNON WHITLOCK, MANDIP SINGH, ANDRÉI SIDOROV, PETER HANNAFORD, Centre for Atom Optics and Ultrafast Spectroscopy, Swinburne University of Technology, Australia — We report the trapping of cold \(^{87}\text{Rb}\) atoms in a 10 \( \mu \text{m} \)-period 1D magnetic lattice constructed from a TbGdFeCo magnetic microstructure on an atom chip. About \( 3 \times 10^3 \) atoms, optically pumped into the \( F=1, m_F = -1 \) ground state to reduce losses due to three-body recombination, are loaded into \( \sim 100 \) lattice sites at \( \sim 10 \mu \text{m} \) below the chip surface with a trap lifetime of \( \sim 12 \) s. Individual clouds in the lattice have been spatially resolved with in-situ absorption imaging. RF spectroscopy measurements at a specific lattice site indicate an atom temperature of \( 1-2 \mu \text{K} \), close to the calculated BEC transition temperature of \( 1.5 \mu \text{K} \) for 2000 atoms. Besides offering potential technical advantages over optical lattices, and the ability to be mounted on an atom chip [1], magnetic lattices can potentially be tailored to arbitrary geometries such as triangular-based and honeycomb lattices [2]. In future work we plan to seek a clear signature of the BEC transition in the multi-lattice traps; study decoherence times for a two-component ultracold gas close to the chip surface using Ramsey interferometry; and implement a 2D magnetic lattice, with periods down to \( \sim 1 \mu \text{m} \) and tailored geometries, using state-of-the-art magnetic microstructure technology, with a view to perform quantum tunneling experiments.


8:24AM T2.00003 Multi-orbital and density-induced tunneling in optical lattices

DIRK-SOEREN LUEHMANN, OLE JUERGENSEN, KLAUS SENGSTOCK, University of Hamburg — We show that multi-orbital and density-induced tunneling have significant impact on the phase diagrams of atoms in optical lattices. In these systems, higher-band processes and off-site interactions constitute an important extension to the established and well-studied Hubbard model. Off-site interactions lead to density-induced hopping, so-called bond-charge interactions, which can be identified with an effective tunneling potential. We introduce dressed operators for the description of multi-orbital renormalized tunneling, on-site, and bond-charge interactions. By means of an extended occupation-dependent Hubbard model, the phase diagrams for bosonic systems and Bose-Fermi mixtures is derived. It substantially deviates from the single-band Hubbard predictions leading to strong changes of the superfluid to Mott-insulator transition point. The presented results have direct relevance for optical lattice experiments with tunable interactions.

8:36AM T2.00004 Swallowtail band structure of the superfluid Fermi Gas in an optical lattice

GENTARO WATANABE, ACPT; POSTECH; RIKEN, SUKJIN YOON, ACPT, DALFOVO FRANCO, Univ. of Trento — We investigate the energy band structure of the superfluid flow of ultracold dilute Fermi gases in a one-dimensional optical lattice along the BCS to BEC crossover within a mean-field approach [1]. In each side of the crossover region, a loop structure (swallowtail) appears in the Bloch energy band of the superfluid above a critical value of the interaction strength. The width of the swallowtail is largest near unitarity. Across the critical value of the interaction strength, the profiles of density and pairing field change more drastically in the BCS side than in the BEC side. It is found that along with the appearance of the swallowtail, there exists a narrow band in the quasiparticle energy spectrum close to the chemical potential and the incompressibility of the Fermi gas consequently experiences a profound dip in the BCS side, unlike in the BEC side.


This work was supported by the Max Planck Society, the Korea MEST, Gyeongsangbuk-Do, Pohang City, for the support of the JRG at ACPT, and ERC through the QGBE grant. Calculations were performed on RICC in RIKEN and Wiggal at the University of Trento.

8:48AM T2.00005 Ultracold Atoms in a Tunable Optical Kagome Lattice

GYU-BOO NG JO, JENNIE GUZMAN, CLAIRE K. THOMAS, PAVAN HOSUR, ASHVIN VISHWANATH, DAN M. STAMPER-KÜRN, University of California Berkeley — Geometrically frustrated systems with a large degeneracy of low energy state are of central interest in condensed-matter physics. The ground state for the kagome antiferromagnet with a particularly high degree of frustration has been proposed to be quantum spin liquid or valence bond solid, but experimental confirmations has been hampered by the significant magnetic disorder and anisotropy of the solid-state kagome magnet. In this talk, I will present the realization of the kagome geometry in a two-dimensional optical superlattice for ultracold \(^{87}\text{Rb}\) atoms [1]. The kagome lattice is obtained by eliminating every fourth site from a triangular lattice of spacing \( a/2 \), with the eliminated sites forming a triangular lattice of spacing \( a \). Our optical kagome lattice allows one to tune the lattice geometry, including kagome, one-dimensional stripe, decorated triangular lattices, thereby controlling the sensitive frustration. Our tunable lattice may offer an ideal platform not only to reveal the nature of the magnetic ground state under controlled frustration, but also to investigate possible crystalline phases in the flat band for bosons.


This work was supported by the NSF and by the Army Research Office with funding from the DARPA OLE program.

9:00AM T2.00006 Supersymmetry in Rydberg-dressed lattice fermions

HENDRIK WEIMER, Harvard University, ITAMP, LIZA HUIJSE, Harvard University, ALEXEY GORSHKOV, Caltech, GUIDO PUPILLO, University of Strasbourg, PETER ZOLLER, University of Innsbruck, IQOQI, MIKHAIL LUKIN, EUGENE DEMPLER, Harvard University — Supersymmetry is a powerful tool that allows the characterization of strongly correlated many-body systems, in particular in the case of supersymmetric extensions of the fermionic Hubbard model [1]. At the same time, these models can exhibit rich and exotic physics on their own, such as flat bands with a vanishing dispersion relation. We show that such lattice models can be realized with Rydberg-dressed fermions in optical lattices. Strong interactions within the ground state manifold of the atoms can be realized by admixing a weak contribution of a highly excited Rydberg state [2]. We discuss the unique possibilities of ultracold atoms for the detection of supersymmetry and the effects of tuning the system away from the supersymmetric point.


9:12AM T2.00007 The Anderson-Higgs Amplitude Mode at the Two-Dimensional Superfluid-Mott Insulator Transition

MANUEL ENDES, TAKEKI FUKUHARA, Max Planck Institute of Quantum Optics, DAVID PEKKER, Department of Physics, Caltech University, MARC CHENEAU, PETER SCHAUSS, CHRISTIAN GROSS, Max Planck Institute of Quantum Optics, EUGENE DEMLER, Physics Department, Harvard University, STEFAN KUHR, University of Strathclyde, SUPA, IMMANUEL BLOCH, Max Planck Institute of Quantum Optics — Anderson-Higgs modes are amplitude oscillations of a quantum field and appear as collective excitations in quantum many-body systems as a consequence of spontaneous breaking of a continuous symmetry. Here we reveal and study an Anderson-Higgs mode in a two-dimensional neutral superfluid close to the transition to a Mott insulating phase. We unambiguously identify the mode by observing a resonance-like feature that shows the expected softening when approaching the quantum critical point. This was made possible by recent advances in the temperature measurement of lattice gases based on single atom detection, which allows us to use lattice modulation spectroscopy as a sensitive tool to probe the many-body system in the linear response regime. We present an experimental and theoretical study of Anderson-Higgs excitations in our system, which also addresses the consequences of reduced dimensionality and spatial confinement.
9:24AM T2.00008 Exploring a geometry-induced phase transition from a superfluid to Mott insulating state in a tunable superlattice , JENNIE GUZMAN, GYU-BOONG JO, CLAIRE THOMAS, PAVAN HOSUR, ASHVIN VISHWANATH, DAN STAMPER-KURN, University of California Berkeley — Ultracold atoms in optical lattices are a promising candidate for the simulation of condensed matter systems due to the fine control over interactions and geometries. Here we present experiments probing the Mott insulator phase transition in a two-dimensional bi-chromatic superlattice using ultracold $^{87}$Rb atoms. The lattice consists of overlaying two commensurate wavelength triangular lattices. By adjusting the relative position of the two lattices, we are able to realize different lattice geometries, including the kagome, the one-dimensional stripe, and the decorated triangular lattice. The superlattice gives a new way to investigate the superfluid to Mott insulating phase transition beyond varying the ratio of the tunneling and interaction energies, J/U. Using this extra degree of control, we investigate a possible geometry-induced phase transition from a superfluid to a Mott insulating state by tuning the number of neighboring sites.

9:36AM T2.00009 Exact solution of SU(4) Kondo Lattice Model for ultracold alkaline-earth atoms , SOLOMON F. DUKI, HONG LING, Department of Physics and Astronomy, Rowan University, 201 Mullica Hill Road, Glassboro, New Jersey 08028 — The recent progress in ultracold atomic physics has greatly spurred the activities aimed at using cold atoms in optical lattices as a unique platform to explore condensed matter phenomena in a highly controlled manner. For alkaline-earth atoms, there is an almost perfect decoupling of the nuclear spin from the electronic angular momentum in both the ground and the metastable states [A. V. Gorskova et al., nature 6, 289 (2010)]. This along with the existence of relatively high nuclear spin degrees of freedom makes the cold alkaline-earth atoms an excellent candidate that one can employ to study Kondo effects with higher SU(N) spin degrees of freedom. In this work we study a mixture of two-component fermionic alkaline-earth atoms loaded in external optical lattice potentials that directly emulates the Lattice Kondo Model under suitable conditions. Using a combination of bosonization and canonical transformation, we find, for a model with SU(4) symmetry, a solvable point where the Hamiltonian of the system can be exactly diagonalized. To characterize the system, we calculate the correlation functions that are accessible by experiments such as time-of-flight.

9:48AM T2.00010 Bose metals on multi-leg ladders with ring-exchange , RYAN V. MISHMASH, UCSB, MATTHEW S. BLOCK, UCSB and UK Lexington, RIBHU K. KAUL, UK Lexington, D.N. SHENG, CSU Northridge, OLEHEI I. MATRUNICHI, Caltech, MATTHEW P.A. FISHER, UCSB — Accessing non-superfluid, uncondensed phases of 2D lattice bosons that conduct and break no symmetries has traditionally been very difficult. Here, we present recent work establishing compelling evidence for the stability of quasi-1D descendants of a particular example of such a “Bose metal.” Specifically, we focus on the so-called “d-wave Bose metal” (DBM), which is crucially characterized by surfaces of gapless excitations in momentum space. Motivated by a strong-coupling analysis of the gauge theory for the DBM, we study in detail a model of hard-core bosons moving on the four-leg ladder with frustrating four-site ring exchange. In this system, we have successfully identified a compressible gapless Bose metal phase with five gapless modes, one more than the number of legs [1]. We can understand the nature of this phase using slave-particle-inspired determinantial wave functions, the properties of which compare impressively well to a DMRG solution of the model Hamiltonian. This represents a significant step forward in establishing the stability of the DBM in two dimensions. Finally, we will discuss scenarios in which such Bose metal-type phases may be realized in present-day experiments on ultracold atomic gases.


Friday, June 8, 2012 8:00AM - 9:48AM — Session T3 Focus Session: Particle Spectroscopy - Grand Ballroom E - Chair: Philip Richerme, Harvard University

8:00AM T3.00001 Fully Differential Study of Fragmentation Dynamics of Li by Ion Impact Using a MotRemi Apparatus , DANIEL FISCHER, Max-Planck-Institut fuer Kernphysik, Heidelberg — The study of atomic fragmentation processes due to charged particle impact provides insight in the dynamics of correlated few-particle Coulomb-systems, and thus advances our understanding of the fundamentally important few-body problem. In this respect, fully differential data represent the most sensitive test of theoretical models. For ion-atom collisions such data became available only in the last decade exploiting the technique of “Reaction Microscopes,” often referred to as cold target recoil ion momentum spectroscopy (COTRIMS). These kinematically complete experiments almost exclusively focussed on the fragmentation of helium and other rare gas atoms, because these targets can easily be prepared with temperatures below 1K using supersonic gasjets. Magneto-optically trapped (MOT) targets of alkaline metals have also been used. However, so far complete studies of ionization have not been possible as magnetic stray fields in the MOT hampered the momentum resolved electron detection. Here we report on the first fully-equipped and functional MotRemi, i.e. a Reaction Microscope with a MOT target. This setup is currently implemented in the ion storage ring TSR at the MPIK in Heidelberg that can provide ion beams with high intensities and very low emittances. Lithium is used as a target which is particularly interesting for its simple, but at the same time asymmetric structure with only one weakly bound outer shell electron and two strongly correlated K-shell electrons. Due to the low temperatures (< 1mK) in the MOT, the momentum resolution achieved in our experiment is drastically improved compared to earlier measurements. We studied single ionization of lithium in collisions with 3 MeV protons and 1.5 MeV/amu O$^{16+}$ ions. Due to the high resolution and by means of optical excitation, for the first time initial state selective cross sections for ion impact ionization became available. Fully differential cross sections of the ionization of 1s, 2s and 2p electrons will be presented.

8:30AM T3.00002 Pseudostate Methods for Treating Atomic Fragmentation Processes Induced by Heavy-Particle Impact , JAMES WALTERS, Queen’s University Belfast — A method for calculating fully differential cross sections that is able to describe any aspect of coincidence measurements involving heavy projectiles will be presented. The method is based upon impact parameter close coupling with pseudostates. Examples from ionization by antiprotons, protons, C$^{6+}$, and gold ions will be shown and compared with experiment.

9:00AM T3.00003 Measuring optical nonlinearities with pump-probe intracavity phase spectroscopy , DAVID CARLSON, JASON JONES, College of Optical Sciences, University of Arizona — A passive femtosecond enhancement cavity (fsEC) is used to make sensitive, time-resolved measurements of phase shifts due to optical nonlinearities. In pump-probe intracavity phase spectroscopy, a strong pump pulse train resonant with a fsEC induces a nonlinear response in a sample which is then detected as a shift of the cavity resonance for a weak counter-propagating probe pulse. Recording this resonant shift allows precise determination of the nonlinear phase shift of the pump pulse relative to the probe. When fsECs are used for high harmonic generation (HHG), a static background plasma can accumulate and frustrate HHG phase matching. To improve the achievable HHG power in these systems it is important to understand the plasma levels and decay timescales. Here we demonstrate the pump-probe technique by measuring the decay of this plasma formed by the ionization of a xenon gas target by the pump pulse.
9:12AM T3.00004 Molecule-surface interactions probed by optimized surface-enhanced coherent Raman spectroscopy. DMITRI VORONINE, ALEXANDER SINYUKOV, XIA HUA, GUOWAN ZHANG, WENLONG YANG, KAI WANG, PANKAJ JHA, GEORGE WELCH, ALEXEI SOLOLOV, Texas A&M University, MARLAN SCULLY, Texas A&M University and Princeton University — Nanoscale molecular sensing is carried out using a time-resolved coherent anti-Stokes Raman scattering (CARS) spectroscopy with optimized laser pulse configurations. This novel technique combines the advantages of an improved spectral resolution, suppressed non-resonant background and near-field surface enhancement of the Raman signal. We detect two species of pyridine in a vicinity of aggregated gold nanoparticles and measure their vibrational dephasing times which reveal the effects of surface environment and molecule-surface interactions on the ultracold molecular dynamics. This technique may be applied to a variety of artificial and biological systems and complex molecular mixtures and has a potential for nanophotonic sensing applications.

9:24AM T3.00005 Ultrafast Electron Diffraction of Laser-Aligned CF₃ molecules. CHRISTOPHER HENSLEY, JIE YANG, MARTIN CENTURION, University of Nebraska – Lincoln — We present first experimental results of electron diffraction from nonadiabatically, laser-aligned molecules in the gas phase. Previous gas-phase diffraction studies have been successful in determining the structure of small molecules by comparing the data to theoretical models of the molecules. The random orientation of the molecules provides only 1D information (the interatomic distances), which makes it difficult to recover the structure of large molecules, or during conformational changes in the molecule where theoretical models cannot provide sufficient information. Using diffraction patterns from multiple projections of the aligned molecules it is possible to reconstruct the complete 3D structure of the symmetric top molecule (CF₃)₂. The alignment angle is adjusted by rotating the direction of the laser polarization. An aligned distribution is created using a femtosecond laser pulse that excites a rotational wave packet causing the molecules to align along the direction of laser polarization around 2 ps after interaction with the laser pulse. Both the electron packet and the intense alignment field are generated using a 300-fs pulse centered at 800 nm. Our results are in good agreement with the previous findings and theoretical models for CF₃⁺.

9:36AM T3.00006 Imaging Polyatomic Molecules in Three Dimensions using Frame Photoelectron Angular Distributions. J B. WILLIAMS, A L. LANDERS, Auburn University, C. TREVISAN, California Maritme Academy, T. JAHNKE, M. S. SCHOFFLER, R. DOERNER, University of Frankfurt, I. BOCHAROVA, F. STURM, C. W. MCCURDY, A. BELKACEM, TH. WEBER, Lawrence Berkeley National Laboratory — We demonstrate a method for determining the full three-dimensional molecular frame photoelectron angular distribution in polyatomic molecules using methane as a prototype. Simultaneous double Auger decay and subsequent dissociation allow measurement of the initial momentum vectors of the ionic fragments and the photoelectron in coincidence, allowing full orientation by observing a three-ion decay pathway, H⁺, H₂⁺, CH⁺. We find the striking result that at low photoelectron energies the molecule is effectively imaged by the focusing of photoelectrons along bond directions.

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1Supported in part by the US DOE Office of Basic Energy Sciences, Division of Chemical Sciences.

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Friday, June 8, 2012 8:00AM - 10:00AM
Session T4 Cold Collisions
Garden 1-2 - Chair: Susanne Yelin, University of Connecticut

8:00AM T4.00001 Chemical Reactions of Li and CaH at 1 Kelvin. VIJAY SINGH, KYLE S. HARDMAN, NAIMA TARIQ, MEI-JU LU, AJA A. ELLIS, MUIR J. MORRISON, JONATHAN D. WEINSTEIN, University of Nevada — Using cryogenic helium buffer-gas cooling, we have prepared dense samples of atomic lithium and molecular calcium monohydride at temperatures as low as 1 Kelvin. We have measured the Li + CaH → LiH + Ca chemical reaction, observed in both the accelerated disappearance of CaH and in the appearance of the LiH molecule. For unpolarized reactants, we have measured a reaction rate coefficient of 3.6 × 10⁻¹⁰ cm³ s⁻¹, with an uncertainty of a factor of 2. The methods of reaction rate measurement and detection of LiH molecules will be presented.

1This material is based upon work supported by National Science Foundation under Grant No. PHY 0900190

8:12AM T4.00002 High Partial Wave Multichannel Quantum Defect Theory for Cold Collisions. BRANDON RUIZIC, JILA - University of Colorado at Boulder, JOHN BOHN, CHRIS GREENE, JILA — We introduce a formulation of multichannel quantum defect theory which is numerically stable for high partial waves at ultracold energies and use this formulation to study Fano-Feshbach resonances in alkali atom collisions. Fano-Feshbach resonances have been observed for a variety of cold collisions, and many of these have been well described by theoretical models. Such measurement of high partial wave resonances could be used to improve precision of theoretical models of scattering. These resonances can be calculated using a full close-coupling scheme, but this method becomes very time-consuming as the number of partial waves grows and the resolution of magnetic field is increased. Multichannel quantum defect theory allows for a much faster and quantitatively accurate calculation of these resonances for alkali atoms.

1This research is funded by the Department of Energy.

8:24AM T4.00003 Investigation of a hybrid quantum system of ultracold atoms and trapped ions. LOTHAR RATSCHBACHER, JONATHAN SILVER, LEONARDO CARCAGNI, CHRISTOPH ZIPKES, CARLO SIAS, MICHAEL KÖHL, University of Cambridge — Hybrid quantum experiments with single ions immersed in quantum gases are starting to be used as versatile systems for experiments in quantum information science, atomic physics and cold chemistry. We deterministically position radio-frequency trapped ¹⁷⁴Yb⁺ ions inside a Bose Einstein condensate of ⁸⁷Rb atoms and achieve independent control on the motional and internal states of both species. We investigate the fundamental atom-ion interactions by characterizing elastic and inelastic collisions and measure their energy-dependent collision rates. In the presence of near resonant light interactions between both species are strongly modified, leading to inelastic scattering rates that are more than three orders of magnitude higher compared to collisions in the ground states. We analyze the process at the single particle level with ion trap mass spectroscopy to identify the underlying interaction channels. The emerging understanding of the state-dependent interactions between the two quantum systems paves the way for applications in quantum information science and cold-matter research.

8:36AM T4.00004 The role of electronic excitation in ultracold atom-ion chemistry. SCOTT SULLIVAN, WADE RELLERGERT, University of California, Los Angeles, SVETLANA KOTOCHIGOVA, Temple University, ERIC HUDSON, University of California, Los Angeles — The role of electronic excitation in chemical reactions between ultracold Ca atoms and Ba⁺ ions confined in a hybrid trap is studied. This prototypical system is energetically precluded from reacting in its ground state, allowing a particularly simple interpretation of the data. It is found that while electronic excitation of the ion can critically influence the chemical reaction rate, electronic excitation in the neutral atom is relatively unimportant. It is experimentally demonstrated that with the correct choice of the atom-ion pair it is possible to mitigate the unwanted effects of these chemical reactions in ultracold atom-ion environments, marking a crucial step towards the next generation of hybrid devices.

1Work supported by NSF grant No. PHY-1005453, ARO No. W911NF-10-1-0505, and AFOSR grant.
8:48AM T4.00005 Interspecies probe of Feshbach molecule formation and stability1. WILL DOWD, ANDERS HANSEN, ALAN JAMISON, ALEXANDER KRAMOV, SUBHADEEP GUPTA, University of Washington — Feshbach resonances are an integral tool in ultracold atomic physics allowing for two-body interaction tuning and molecular dimer formation. The two lowest energy states of the $^6$Li atom exhibit a broad Feshbach resonance at 834 Gauss which can be utilized to link pairs of atoms into dimers. We study the formation and dynamics of shallow Li$_2$ Feshbach dimers in the presence of a second species, $^{171}$Yb, at ultracold temperatures. The collisional stability of the Li-Yb mixture is adequate to allow time-resolved studies of these interactions. We will report on the observed modifications of Li$_2$ formation and stability due to the presence of Yb, as well as the concomitant effect on the Yb gas.

1This work was supported by the NSF and Sloan Foundation

9:00AM T4.00006 Recent results on a new method for producing ultracold molecular ions1. WADE RELLERGERT, SCOTT SULLIVAN, University of California - Los Angeles, SVETLANA KOTOCHIGOVA, Temple University, KUANG CHEN, STEVEN SCHOWALTER, ERIC HUDSON, University of California - Los Angeles — We present recent results from our experimental effort to produce ultracold, internal ground-state BaCl$^+$ ions using a Ca MOT. The method utilizes sympathetic cooling due to the strong collisions between co-trapped molecular ions and laser-cooled neutral atoms which should efficiently cool both the internal and external molecular ion degrees of freedom. Samples of such ultracold molecular ions find applications in ultracold chemistry, precision measurement and quantum computation.

1Work supported by NSF grant No. PHY-1005453, ARO No. W911NF-10-1-0505, and AFOSR grant.

9:12AM T4.00007 Non-reactive collisions of sodium and silver atoms with nitrogen molecules2. JEROME LOREAU, ITAMP; HARRISON-.SMITHsonian Center for Astrophysics, PENG ZHANG, ITAMP, Harvard-Smithsonian Center for Astrophysics and Duke University, ALEX DALGARNO, ITAMP, Harvard-Smithsonian Center for Astrophysics and Duke University — We present a quantal study of elastic and rotationally inelastic collisions of Na and Ag with N$_2$ for energies between 0.1 and 5000 cm$^{-1}$. We obtain the two-dimensional potential energy surface of the ground state of the NaN$_2$ and AgN$_2$ complexes using CCSD(T) methods with the nitrogen molecule frozen at its equilibrium geometry. Using these potentials, we compute the rotationally elastic and inelastic scattering, differential, and momentum transfer cross sections for several initial rotational levels using the close-coupling approach. We also investigate the temperature dependence of the rates corresponding to these collisions. We discuss the importance of sodium-nitrogen collisions in the study of laser guide stars as well as the possibility of substituting Ag for Na in experiments by comparing the cross sections and rates for both systems.

2Supported by the BAEF and the US Department of Energy

9:24AM T4.00008 Zeeman Relaxation in Cold Aluminum–Helium and Antimony–Helium Collisions, YAT SHAN AU, COLIN CONNOLLY, EUNMI CHAE, TIMUR TSCHERBUL, JOHN DOYLE, Harvard University — We present the combined experimental and theoretical study of aluminum–helium and antimony–helium collisions at 800mK. Zeeman relaxation in atom–helium collisions can serve as a probe of the atom–helium interaction potentials. The relaxation mechanisms are different for the two species. In the case of aluminum, due to a spherical electron distribution, Zeeman relaxation is expected to be slow in the pure $^2P_{1/2}$ ground state. However, during a collision the anisotropic $^2P_{1/2}$ excited state is mixed with the ground state, causing rapid relaxation. Our results further confirm the theoretical model previously developed for indium and gallium. In the case of antimony, despite being nominally a spherical S–state ($^4S_{3/2}$), spin–orbit coupling mixes states with nonzero angular moment into the ground state, and hence introduces electronic anisotropy into its interaction with helium. This work extends our understanding of cold collisions in pnictogens.

9:36AM T4.00009 Charge transfer processes in ultracold atom-ion collisions1. DIEGO VALENTE, ROBIN CÔTE, University of Connecticut — We investigate charge transfer processes occurring in ultracold collisions of atoms and ions, and explore the effect of external magnetic fields. Our calculations include hyperfine interactions between the ion and the neutral atoms. We discuss how these interactions affect scattering processes, and may lead to detectable resonances. These resonances can be used to control charge transfer which may have applications to quantum information processing. We present results for collisions between various alkaline-earth atom-ion systems.

1Supported by the National Science Foundation Grant No. 1110254.

9:48AM T4.00010 Single trapped ions sympathetically cooled by ultracold atoms. ARNE HAERTER, ANDREAS BRUNNER, ARTJOM KRUÉKOW, STEFAN SCHMID, WOLFGANG SCHNITZLER, JOHANNES HECKER DENSCHLAG, Institute of Quantum Matter, Ulm University — We investigate the interaction of single trapped ions ($^{138}$Ba$^+$ or $^{87}$Rb$^+$) with an ultracold cloud of optically confined $^{87}$Rb atoms. In these experiments, the ion is held in a linear Paul trap and is immersed in the center of the atomic cloud. The atom-ion interaction gives rise to a strong and long-range $\frac{1}{r}$ polarization potential yielding novel and complex interaction dynamics. Charge transfer processes and elastic scattering have been observed at millikelvin collision energies [1,2], the energy scale being set by the trap-driven excess micromotion of the ion. Using improved field compensation techniques, we reduce the energy of the excess micromotion to the Ba$^+$ sub-Doppler regime ($\approx 250-300 \mu K$) and examine the influence of ion micromotion energy over a wide range. In performing these experiments on $^{87}$Rb$^+$ ions we show the applicability of this buffer-gas cooling method to ionic species not amenable to laser cooling. By decreasing the ion energy even further we are aiming at novel experiments, such as the production of ultracold, charged molecules in a well-defined quantum state.


Friday, June 8, 2012 8:00AM - 10:00AM — Session T5 Matter-Wave Interferometry I Garden 3 - Chair: A. Kumarakrishnan, York University

8:00AM T5.00001 A Novel Cavity-Based Atom Interferometer, JUSTIN BROWN, BRIAN ESTEY, HOLGER MÜLLER, University of California Berkeley — The world’s leading atom interferometers are housed in bulky atomic fountains. They employ a variety of techniques to increase the spatial separation between atomic clouds including high order Bragg diffraction. The largest momentum transfer in a single Bragg beamsplitter has been limited to 24 $hk$ by laser power and beam quality. We present an atom interferometer in a 40 cm optical cavity to enhance the available laser power, minimize wavefront distortions, and control other systematic effects symptomatic to atomic fountains. We expect to achieve spatial separations between atomic trajectories comparable to larger scale fountains within a more compact device. We report on our progress in developing this new interferometer using cold Cs atoms and discuss its prospects for exploring large momentum transfer up to 100 $hk$ in a single Bragg diffraction process. The compact design will enable the first demonstration of the gravitostatic Aharonov-Bohm effect.
8:12AM T5.00002 High data-rate atom interferometer for measuring acceleration¹, AKASH RAKHOLIA, University of New Mexico, HAYDEN MCGUINNESS, GRANT BIEDERMANN, Sandia National Laboratories — Atom interferometers have the potential to be exceptional broadband inertial sensors in both translational and rotational degrees of freedom. The demonstrated performance of this technology rivals the best ring-laser gyroscopes and falling corner-cube gravimeters. However, compact and field-worthy manifestations of atom interferometers remain elusive using standard approaches. Furthermore, bandwidths have typically been limited to a few Hertz, which is insufficient for a broader application space. We demonstrate a high data-rate light-pulse atom interferometer for measuring acceleration. The device is optimized to operate at rates between 50 Hz to 330 Hz with sensitivities of 0.57 micro-g/rtHz to 36.7 micro-g/rtHz, respectively. Our method offers a dramatic increase in data rate and demonstrates a path to new applications in highly dynamic environments.

¹This work was supported by Laboratory Directed Research and Development at Sandia National Laboratories.

8:24AM T5.00003 Measurements of gravitational acceleration from an echo atom interferometer¹, C. MOK, A. CAREW, B. BARRETT, R. BERTHAUME, A. KUMARAKRISHNAN, Department of Physics and Astronomy, York University — We have developed two techniques involving a ground-state, time-domain echo atom interferometer (AI) to measure gravitational acceleration, g, from a sample of laser-cooled atoms. We compare and contrast measurements from a two-pulse and a three-pulse stimulated-echo AI described in PRA 84, 063623 (2011). The two-pulse AI involves excitation by standing wave pulses separated in time by T₁, and detection at 2T₁. In this case, the accumulation of the matter-wave fringes as a function of T₁ is described by a frequency chirped signal analogous to the interference fringes recorded by a falling corner-cube Mach-Zehnder optical interferometer. In contrast, the three-pulse stimulated echo AI requires excitation by standing wave pulses separated by T₁, T₂, and detection at 2T₁ + T₂. In this case, the signal from the AI as a function of T₂ is modulated at a single frequency determined by T₁. Since the three-pulse AI is less sensitive to mirror vibrations and magnetic gradients, the measurement timescale is appreciably increased. We also consider the implementation of a RF-optical feedback loop to actively stabilize both AIs from the effects of mirror vibrations.

¹Work supported by CFI, OIT, NSERC, and York University

8:36AM T5.00004 Progress towards a test of the universality of free fall using a ⁶Li-⁷Li atom interferometer, PAUL HAMILTON, TOM BARTER, GEENA KIM, BISWAROOP MUKHERJEE, HOLGER MÜLLER, University of California at Berkeley — Measurements of the acceleration of gravity for bodies of differing compositions have long been used to test the universality of free fall (UFF), one part of the equivalence principle underlying general relativity. A ⁶Li-⁷Li matter wave interferometer test of UFF would have high sensitivity to new physics because of the relatively large difference between ⁶Li and ⁷Li nuclei [1]. An optical lattice will be loaded with ⁶Li and ⁷Li atoms from a dual species 2D/3D-magneto-optical trap. The lattice will then be employed both as a waveguide to prevent atom losses due to the high thermal velocity of Li, and as large momentum transfer beam splitters in analogy to the Bloch-Bragg-Bloch beam splitters already developed by us [2,3]. We anticipate an accuracy of 10⁻¹⁴g for the differential acceleration measurement. We discuss investigations of novel all-optical cooling of lithium using degenerate Raman sideband cooling as well as recent progress towards a demonstration of the first ultracold lithium interferometer.


8:48AM T5.00005 Towards Testing General Relativity with a dual species interferometer, DENNIS SCHLIPPERT, JONAS HARTWIG, DANIEL TIARKS, ULRICH VELTE, SVEN GANŠKE, WOLFGANG ERTMÉR, ERNST M. RASEL, Institut fuer Quantenoptik, Leibniz Universitaet Hannover — We report on our work directed towards a dual species matter-wave interferometer for performing a differential measurement of the acceleration of free falling ⁸⁷Rb and ⁴⁰K atoms to test Einstein’s equivalence principle (universality of free fall). Based on minimal Standard Model Extension calculations this combination of test masses is more sensitive to composition based equivalence principle violating effects than, e.g., ⁸⁷Rb-⁸⁷Rb. During free fall, a Mach-Zehnder type interferometry sequence employing stimulated Raman transitions is applied synchronously for both species, achieving high common noise rejection. With an expected single shot resolution of 5 x 10⁻⁹g the apparatus will allow for studying systematics at the 10⁻⁹g level after 100 s integration time. Post-correction methods for high vibrational noise environments are investigated. To assure well defined starting conditions the two species will be trapped in an optical dipole trap. The properties of this trap at 2 μm allow for fast and efficient laser cooling, use of evaporative and sympathetic cooling techniques is possible. We will show the environmental noise limited performance of the single species Rb gravimeter and the progress of the implementation of the K gravimeter.

9:00AM T5.00006 Large momentum transfer atom interferometry with Coriolis force compensation, PEI-CHEN KUAN, SHAU-YU LAN, BRIAN ESTEY, University of California, Berkeley, PHILIPP HASLINGER, University of Vienna, HOLGER MUELLER, University of California, Berkeley — Light-pulse atom interferometers use atom-photon interactions to coherently split, guide, and recombine freely falling matter-waves. Because of Earth’s rotation, however, the matter-waves do not recombine precisely, which causes severe loss of contrast in large space-time atom interferometers. I will present our recent progress in using a tip-tilt mirror to remove the influence of the Coriolis force from Earth’s rotation. Therefore, we improve the contrast and suppress systematic effects, also reach what is to our knowledge the largest space-time area.

9:12AM T5.00007 A Schroedinger Cat Matter Wave Gyroscope Using Collective Excitation of Atomic Ensembles, SELIM SHAHRIAR, RESHAM SARKAR, MAY KIM, YANFEI TU, Northwestern University — The phase shift in an atom interferometric gyroscope (AIG) of area A, induced by a rotation rate of Ω, is given by δϕ = 2AΩm/ħ, where m is the mass of the atom. This is seen transparently when we consider the time delay (computed using special relativistic dynamics) between the signals arriving at a detector, given by δt = 2AΩC². The phase shift is found by multiplying the delay by the Compton frequency, mC²/h. The fact that the Compton frequency of an alkali atom is nearly ten orders of magnitude larger than a typical optical frequency is the basic reason why an AIG is much more sensitive than an optical gyroscope. In this talk, we describe a matter-wave gyroscope with a Compton frequency much larger than that of a single atom. Here, an ensemble of atoms is excited by two counter-propagating Raman beams corresponding to a Λ transition. In the limit of symmetrized collective excitation, the ensemble can then be split, with a recoil of 2qh/(Nm), where N is the number of atoms in the ensemble. Using the standard π/2-π-π/2 excitation sequence results in a gyroscope with δϕ = 2AΩNm/h, since the Compton frequency is larger by a factor of N.
9:24AM T5.00008 Superfluid rotation sensor with helical laser trap. ALEXEY OKULOV. Russian Academy of Sciences — The macroscopic quantum states of cold atomic ensembles in helical laser traps are considered in the framework of the Gross-Pitaevskii equation. The helical interference pattern is composed of the two counter-propagating Laguerre-Gaussian optical vortices with opposite orbital angular momenta and they are driven in rotation via angular Doppler effect. The macroscopic observables including linear momentum and angular momentum are evaluated explicitly.


9:36AM T5.00009 Rotation measurement using a grating-echo interferometer1, ADAM CAREW, BRYNLE BARRETT, A. KUMARAKRISHNAN, Department of Physics and Astronomy, York University — We discuss a proof-of-principle measurement of rotation using a grating echo atom interferometer. Cold atoms are launched horizontally across the excitation beams and rotation is measured as a phase shift in the echo signal due to the Sagac effect. Radiofrequencies for the excitation beams are derived from phase-locked loops, referenced to a Rubidium clock. These excitation beams are pulsed, counter-propagating, blue-detuned travelling waves, having a small frequency difference (Δf) with respect to each other. The experiment requires the application of two such pulses, separated by t=T, with the second pulse having opposite k-vectors to the first. The atomic density grating formed in the vicinity of t=2T is detected by applying a travelling-wave read-out pulse, in the presence of a counter-propagating interrogation pulse, which is detuned from the readout by 10 MHz. The effect of rotation manifests as a phase shift in the beat note between the interrogation beam and the back-scattered signal. The magnitude of the Sagac shift is varied by changing the launch velocity of the atomic cloud. Averaging the signal as a function of Δf over T generates a ground-state Ramsey fringe pattern with a shifted central fringe.

1Work supported by: CFI, OIT, NSERC and York University

9:48AM T5.00010 Sagac Interferometry with Bose-Einstein Condensates in a Uniformly Rotating Ring Trap1, MARTY KANCES, Computational Science Research Center, San Diego State University, San Diego, California 92182-1245, MICHAEL BROMLEY, Centre for Quantum-Atom Optics, School of Mathematics and Physics, The University of Queensland, Brisbane QLD 4075, Australia — We present the results of numerical simulations studying a novel scheme to perform Sagac interferometry with Bose-Einstein condensates in a uniformly rotating ring trap. The proposed scheme involves determining the relative phase shifts between two counter-propagating condensate wavepackets as the angular velocity of the ring trap is varied. Analyzing the interference patterns obtained from the simulations, we find that, for the most part, the phase shift response closely follows that predicted by the Sagac effect, even when the nonlinear mean-field interaction of the condensate is large. However, we unexpectedly find that the linear accumulation of the relative phase shift with respect to time manifests itself as step-like phase jumps during collisions of the wavepackets, with the magnitude of the phase jumps being linearly dependent upon the angular velocity of the rotating ring trap and the angular momenta of the wavepackets. We provide details of the proposed scheme and discuss some of the advantages this unexpected behavior in the phase shift response may offer in performing Sagac interferometry with Bose-Einstein condensates in the future.

1Supported in part by SDSU, Cymer Incorporated, the ARCS Foundation, the Inamori Foundation, NSF grants PHY-0970127 and CHE-0947087, and the ARC Future Fellowship (FT10010905) program.

Friday, June 8, 2012 8:00AM - 10:00AM
Session T6 Entangled States of Photons and Atoms Garden 4 - Chair: Poul Jessen, University of Arizona

8:00AM T6.00001 Standard Polarization-Maintaining Fibers as a Source of Polarization-Entangled Photons, VIRGINIA LORENZ, BIN FANG, OFFIR COHEN, JAMY MORENO, University of Delaware — Entangled photons are a crucial resource for quantum communication, quantum computation and fundamental tests of quantum mechanics, which often require the distribution or processing of entangled photons through single-mode fiber (SMF) networks. However, coupling into SMFs has been a challenge due to the spatial mode mismatch between the created photons and the guided mode in the SMF. Recently, it was demonstrated that efficient generation of photon-pairs at visible wavelengths is possible using standard, commercially available polarization-maintaining fibers (PMFs), with high coupling efficiency into SMFs. Here we demonstrate the capability of the source to generate polarization-entangled photon-pairs by inserting a PMF source into a Sagac interferometer. With a total pump power of 10mW of ~200fs pulses at 715nm and 80MHz, we obtain 350 coincidences/s of photons at 850nm and 620nm. We perform a quantum state tomography to reconstruct the density matrix, yielding, without background subtraction, a tangle of T = 0.629 ± 0.022, a linear entropy of S = 0.264 ± 0.014, and a fidelity with a maximally entangled state of 90.40 ± 0.56%, clearly exhibiting non-classical entanglement. We expect this source to be useful for fiber-based quantum communication protocols.

8:12AM T6.00002 A Miniature Ultrabright Source of Long Biphotos, CHIH-SUNG CHUU, Stanford University and National Tsing Hua University, G.Y. YIN, STEPHEN E. HARRIS, Stanford University — An ultrabright compact source of long biphotoons is essential for scalable quantum networks. Here we report the generation of long biphotos utilizing the cluster effect in a monolithically doubly resonant parametric down-converter. The biphoto generation rate and spectral brightness are 110 and 41 times larger, respectively, than previously reported. This source will find applications in quantum repeater protocols.

8:24AM T6.00003 Quantum Interference between nondegenerate entangled photons1, CHANG LIU, J.F. CHEN, SHANCHAO ZHANG, SHU-YU ZHOU, Department of Physics, The Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong, China, YOON-HO KIM, Department of Physics, Pohang University of Science and Technology (POSTECH), Pohang 790-784, Korea, M.M.T. LOY, G.K.L. WONG, SHENGWANG DU, Department of Physics, The Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong, China — We generate narrow-band entangled photon pairs from laser cooled atoms in a right-angle geometry and study their Hong-Ou-Mandel (HOM) two-photon quantum interference. When the two paths are balanced before the beam splitter, we observe a perfect destructive interference for both degenerate and nondegenerate photons. In particular, our results show that the path-exchange symmetry plays a more general critical role for observing the HOM interference, rather than the temporal or frequency indistinguishability of the photons and their simultaneous arrival at the beam splitter. The interference between the indistinguishable Feynman pathways leads to the HOM effect for both degenerate and nondegenerate paired photons. Furthermore, we also show that the quantum beat between nondegenerate photons can be measured with slow detectors by varying the relative path length difference, in addition to the direct observation of the quantum beat with fast detectors in an unbalanced-path configuration. Our results may lead to potential applications in linear optical quantum information processing involving photons at different wavelengths.

1The work was supported by the Hong Kong Research Grants Council (Project No. 600809).
of New Mexico — Spin squeezed states have applications in metrology and quantum information processing. Most spin squeezing research to date has focused

CQuIC University of New Mexico, COLLIN TRAIL, University of Calgary, POUL JESSEN, CQuIC University of Arizona, IVAN DEUTSCH, CQuIC University

Metrology

a path-entangled number state known as \( M \) & \( M' \) limit was considered as the fundamental limitation on measurements made with light beams for long. Using non-classical states of light, this precision can be improved to the Heisenberg limit. Unfortunately, highly correlated quantum states of light are very fragile with respect to noise. In 2008, Huver introduced a path-entangled number state known as \( \text{M&M'} \) state, \( \left| M : M' \right\rangle_{a,b} = \left( \left| M \right\rangle_{a} + \left| M' \right\rangle_{a} \right) / \sqrt{2} \), which is more robust to loss than \( \text{N00N} \) states possessing all photons in either mode. In this talk, we give a detailed discussion of quantum states for optical two-mode interferometers with definite photon number in the presence of photon losses. We calculate an expression for the quantum Fisher information as well as the Quantum Cramer-Rao Bound for optical two-mode Interferometers of \( \text{M&M'} \) states with loss.

9:00AM T6.00006 Fringe visibility and Which-Way information for Robust Entangled Fock states, KEBEI JIANG, MOOCHEH KIM, CHASE BRIGNAC, HWANG LEE, JONATHAN P. DOWLING, Louisiana State University — It has been shown that \( \text{mm} \) states, a class of path-entangled Fock states which have non-zero photon numbers on both arms of a two-mode interferometer, are robust against photon loss to a certain degree. To explain the reason for such robustness we calculate which-way information, the visibility of interference fringe and the degree of entanglement for \( \text{mm} \) states in a two-mode interferometer. We go on to derive a complementarity relation between these quantities. We show that less which-way information is revealed by using \( \text{mm} \) states than \( \text{N00N} \) states. This is because of the decoyed photons which are present in both arms of the interferometer. Hence \( \text{mm} \) states provide better visibility.

9:12AM T6.00007 Using a CNOT gate to improve detector efficiency, KATHERINE BROWN, Louisiana State University, BEN FORTESCUE, Southern Illinois University, MOOCHEH KIM, CHRIS RICHARDSON, JONATHAN DOWLING, Louisiana State University — One of the most significant problems with photonic quantum computing is that of photon loss. Unfortunately detecting, and correcting for photon loss is made considerably more difficult due to the problem of inefficient photon detectors, which often have a detection efficiency far lower than that required for standard quantum error correction. In this presentation we will consider the problem of trying to detect the state of a photon at the end of our calculation with detectors that only have an efficiency of 90%. In particular we will consider how entangling quantum gates can be used to boost the efficiency of the lossy detectors, and how this affects the accuracy of the result that can be obtained. We will compare two different procedures, one which allows us to determine whether the photon we are aiming to detect has been lost before or during the detection procedure, and the other which replaces a photon loss error with a bit flip error. This will allow us to show the trade off between detectable errors, and undetectable errors, something important to consider in quantum error correction.

9:24AM T6.00008 Phase estimation with two-mode squeezed vacuum and parity detection: Bayesian analysis, KEITH MOTES, Louisiana State University, PETR ANISIMOV, Stony Brook University, JONATHAN DOWLING, Louisiana State University — Using Bayesian analysis we characterized the performance of phase estimation in the Mach-Zehnder interferometer with two-mode squeezed vacuum input. Phase uncertainty, averaged over many trials, is examined and the dependence on photon number is found. As we continue investigating our results we hope to determine the ideal average number of photons to use in a MZI with TMSV and compare it with shot-noise and Heisenberg limited sensitivity. Our scheme works well for small unknown phases but requires a large number of trials and a small number of input photons. In actual implementations of the scheme, a control phase \( \psi \) has to be implemented to maintain unknown phase difference at the “sweet spot.”

9:36AM T6.00009 Enhanced Spin Squeezing Through Quantum Control of Qudits\(^1\), LEIGH NORRIS, CQuIC University of New Mexico, COLLIN TRAIL, University of Calgary, POUL JESSEN, CQuIC University of Arizona, IVAN DEUTSCH, CQuIC University of New Mexico — Spin squeezed states have applications in metrology and quantum information processing. Most spin squeezing research to date has focused on ensembles of qubit spins. We explore squeezed state production in an ensemble of spin \( f=1/2 \) alkali atoms (qudits). Collective interactions are achieved through coherent quantum feedback of a laser probe, interacting with the ensemble through Faraday interaction. This process is enhanced with control of the atomic qudits, both before and after the collective interaction. Initial preparation increases the collective squeezing parameter through enhancement of resolvable quantum fluctuations, but comes at the price of increased decoherence. We find an optimal state preparation, achieving an increased squeezing parameter while remaining robust to decoherence. After the collective interaction, qudit control maps generated entanglement to different pseudo-spin subspaces where it is metrologically useful, e.g., the clock transition or the stretched state for magnetometry. These considerations highlight the unique capabilities of our platform: we can transfer correlations between subspaces to explore a wider variety of nonclassical states, with ultimate application in sensors or quantum information processors.

\(^1\)Supported by NSF PHY-0969997.

9:48AM T6.00010 Towards single atoms in an optical dipole trap using Rydberg blockade\(^2\), X.L. ZHANG, A.T. GILL, M. GIBBONS, L. ZHANG, L. ISENHOWER, T.G. WALKER, M. SAFFMAN, University of Wisconsin — We present experimental studies of preparation of single atom occupancy of optical dipole traps using Rydberg blockade of few atom samples. Starting with \( N \) atoms in the \( F = 2 \) state of \( ^{87}\text{Rb} \) we perform stimulated Raman transfers to \( F = 1 \) via a highly excited Rydberg state. Single atom occupancy is obtained with better than 50% probability. The results are compared with a numerical model accounting for the atomic interactions which predicts the possibility of \( \sim 80\% \) single atom loading starting from samples with \( N \sim 10 \) atoms.

\(^2\)This work was supported by the NSF and the AFSOR MURI program.

Friday, June 8, 2012 8:00AM - 10:00AM –
Session T7 Photoionization or Photofragmentation of Heteronuclear Molecules
Terrace - Chair: Ali Belkacem, Lawrence Berkeley National Laboratory
8:00AM T7.00001 Orientation dependence of the ionization of CO and NO in an intense femtosecond two-color laser field1, HUI LI, DIPANWITA RAY, SANKAR DE, WEI CAO, GUILLAUME LAURENT, ZHENHUA WANG, ANH THU LE, C. LEWIS COCKE, J.R. Macdonald Laboratory, Department of Physics, Kansas State University, IRINA ZNAKOVSKAYA, Max-Planck Institut for Quantenoptik, MATTHIAS KLING, Kansas State University and Max-Planck Institut für Quantenoptik — Two-color (800 nm and 400 nm) ultrashort (30±10 fs) laser pulses were used to ionize and dissociate CO and NO. The emission of C⁺⁺, N⁺⁺ and O⁺⁺ fragments were measured with a velocity-map-imaging (VMI) system. The data show that the ionization rate is dependent on the orientation of the molecules with respect to the laser polarization. Both molecules ionize more easily when the electric field points from C to O in CO and from N to O in NO. The asymmetry of emission is much higher for CO than for NO. The sign of the asymmetry is not strongly dependent on kinetic energy release (KER). The favored ionization orientation is in agreement with the expectation of the molecular orbital Ammosov-Delone-Kralev (MO-ADK) [1] theory and with a Stark-corrected version of a strong-field-approximation (SFA) calculation [2].


1This work was supported by DOE. Additional thanks of W.C. for NSF-CHE-0822646, G.L. for MURI-W911NF-07-1-0475, and H.L. for NSF-EPS-0903806.

8:12AM T7.00002 Molecular dissociation of HD⁺ by broad bandwidth chirped laser pulses: a molecular bandwidth filter1, M. ZOHRABI, U. ABLIKIM, K.D. CARNES, B.D. ESRY, I. BEN-ITZHAK, J.R. Macdonald Laboratory, Department of Physics, Kansas State University, Manhattan, KS 66506 — We employ a coincidence 3D momentum imaging method to study the fragmentation of HD⁺ following interaction with an intense, 800 nm, 25 fs Fourier transform-limited (FTL) laser pulse. The broad bandwidth of our FTL pulse prevents us from observing vibrational peaks that we would expect to see using longer FTL laser pulses ~100 fs. However, by chirping the pulse either positively or negatively, while maintaining a fixed bandwidth, we were able to measure vibrational structure. The kinetic energy release of these vibrational peaks are shifted up or down depending on the sign of the chirp[4]. We will address the question of why the vibrational structure is observed in spite of the broad bandwidth of the chirped laser pulses.

1Supported by the Chemical Sciences, Geosciences, and Biosciences Division, Office of Basic Energy Sciences, Office of Science, U.S. Department of Energy.


8:24AM T7.00003 Auger spectrum of a water molecule after single and double core ionization1, LUDGER INHESTER, CARL F. BURMEISTER, GERRIT GROENHOF, HELMUT GRUBMUELLER, Max Planck Institut für Biophysikalische Chemie — The high intensity of Free Electron Lasers (FEL) opens up the possibility to perform single-shot molecule scattering experiments. However, even for small molecules radiation damage induced by absorption of intense x-ray radiation is not yet fully understood. To provide insight into this process, we have studied the dynamics of water molecules in single and double core ionized states by means of electronic transition rate calculations and ab initio molecular dynamics (MD) simulations. From MD trajectories photoionization and Auger transition rates were computed based on electronic continuum wavefunctions obtained by explicit integration of the coupled radial Schrödinger equations. To account for the nuclear dynamics during the core hole lifetime, the calculated electron emission spectra for different molecular geometries were accumulated according to the obtained time-dependent populations. We find that, in contrast to the single core ionized water molecule, the nuclear dynamics for the double core ionized water molecule during the core hole lifetime leaves a clear fingerprint on the electron emission spectra. In addition, the lifetime of the double core ionized water was found to be significantly shorter than half of the single core hole lifetime.

8:36AM T7.00004 Molecular Frame Photoelectron Angular Distributions as a Probe of Geometry and Auger Dissociation Dynamics1, CYNTHIA S. TREVISAN, California Maritime Academy, THOMAS N. RESCIGNO, Lawrence Berkeley Nat. Lab, C. WILLIAM MCCURDY, Univ. Cal. Davis — Complex Kohn variational calculations of the molecular frame photoelectron distributions (MFPADs) for 1s core ionization of CH₂, NH₃, and H₂O are presented for ejected electron energies below 25 eV. Surprisingly, in these three cases there are energy ranges in which the photoelectron MFPADs effectively form “images” of the molecular geometry. Comparison with recent momentum imaging experiments on methane at the Advanced Light Source verify this effect. Simultaneous double Auger decay in these molecules can produce dissociation into three charged fragments, e.g., CH₂ + 2 H⁺, allowing the complete orientation of the molecule and therefore the measurement of 3D MFPADs that test these predictions. In other Auger decay channels the measurement of 3D MFPADs verifies axial recoil (prompt dissociation) or probes its absence in the Auger dissociation dynamics of small molecules.

1Work Supported by DOE Basic Energy Sciences

8:48AM T7.00005 Photo double ionization of acetylene and subsequent fragmentation pathways1, B. Gaire, P. Braun, I. Bocharova, F. Sturm, D. Haxton, A. Belkacem, TH. WEBER, Lawrence Berkeley National Laboratory, C.L. COCKE, J.R. Macdonald Laboratory, Kansas State University, A. LANDERS, Department of Physics, Auburn University, R. DORNER, University of Frankfurt — We have investigated the photo double ionization of acetylene (C₂H₂) molecules using photons of 42eV energy. Coincident measurements of both ions and electrons with the COLd Target Recoil Ion Momentum Spectroscopy (COLTRIMS) method make kinematically complete study possible. We extract the 3d-momentum vectors of each particle using the measured flight time to the detector and the position on the detector. We identify the fragmentation pathways by using the measured energy of the photo electrons, kinetic energy release of the nuclear fragments, photon energy, and the ionization potential for a specific dication state evaluated from theory. We mainly discuss the pathways leading to the symmetric breakup (CH⁺/CH⁺), the deprotonation (H⁺/C₂H⁺) and the quasi-symmetric fragmentation (C⁺⁺/H₂C⁺). We explain the importance of such pathways for the study of the time dependent dynamics of the fragmentation.

1Supported by the Division of Chemical Sciences, Office of Basic Energy Sciences, U.S. Department of Energy.
9:00AM T7.00006 Imaging Molecular Isomerization Using Molecular-Frame Photoelectron Angular Distributions

T.N. RESCIGNO, LBNL, A.E. OREL, NICOLAS DOUGUET, UC Davis — Techniques such as X-ray diffraction and ultrafast electron diffraction can potentially be taken to the time domain to image chemical reactions on their natural timescale. Photoelectron diffraction from fixed-in-space molecules, where an electron is launched from an inner shell by photoabsorption, offers a similar promise. We illustrate the idea here with the results of ab initio calculations using the complex Kohn variational method of molecular-frame photoelectron angular distributions (MFPADs) on the acetylene monocation (HCCH+). Photoionization of neutral acetylene, which is linear at equilibrium, in the 20-40 eV range produces ground (X) and excited (A) HCCH+ in roughly equal amounts. The electronically excited A-state cation can follow a downhill path to a conical intersection with the X-state near a trans-symmetric geometry and from there to a vinylidene (H2CC) isomeric structure. We will show that the MFPADs produced by C k-shell photoionization of HCCH+, while relatively insensitive to the electronic configuration of the valence electrons at a given photoelectron energy, are much more sensitive to nuclear geometry and can therefore be used to track the acetylene to vinylidene isomerization.

1Work performed under auspices of US DOE by LBNL and supported by OBES Division of Chemical Sciences.

9:12AM T7.00007 Time-resolved molecular frame photoelectron angular distribution: Snapshots of acetylene and ethylene isomerizations

NICOLAS DOUGUET, University of California Davis, THOMAS RESCIGNO, Lawrence Berkeley National Lab, ANN OREL, University of California Davis — It has been proposed that chemical reactions can be imaged by detection of a photoelectron in the molecular fixed body frame (MFPAD), following either valence or K-shell photoionization. We will contrast these two techniques using acetylene and ethylene isomerization as examples. The ab initio calculations were carried out using the complex Kohn variational method. Our results indicate that while K-shell MFPADs are only sensitive to molecular geometry whereas valence MFPADs are sensitive to both geometry and the initial electronic state of the target. Both examples show that isomerization takes place via conical intersections. However, acetylene requires an excitation/ionization step, while ethylene undergoes isomerization following direct excitation of the neutral V state.

2This work performed under the auspices of the DOE and supported by the Office of Basic Energy Science, Division of Chemical Sciences.

9:24AM T7.00008 Intense-field Ionization and Fragmentation of Heterocyclic Organic Molecules: the Azabenzenes

TIMOTHY SCARBOROUGH, COLLIN MCACY, DAVID FOOTE, CORNELIS UITERWAAL, University of Nebraska - Lincoln — We report on the ultrafast intense-field photoionization and fragmentation of pyridine, pyridazine, pyrimidine and pyrazine. These four molecules represent a systematic series of perturbations into the structure of a benzene ring which explores the substitution of a C-H entity with a nitrogen atom, creating a heterocyclic structure which remains isoelectronic with benzene. Other than pyridine, each molecule has the same chemical formula, with the only difference being the relative placement of the two perturbing nitrogen atoms (ortho-, meta- or para-substitutions). Data is recorded under intense-field, single-molecule conditions. 50 fs, 800 nm pulses are focused into the molecular vapor, and ion mass spectra are recorded for intensities of 10¹⁰ to 10¹⁵ W/cm² in the absence of the focal volume effect. For all targets, stable singly- and doubly-charged parent ions (C₆₋ₙH₄₋ₙNₙ⁺(+)) are observed with features suggesting resonance enhancement (REMPI). Fragmentation dynamics differ greatly between molecules, with each species showing evidence of metastable decay processes.

3This material is based upon work supported by the National Science Foundation under Grant No. PHY-0355235.

9:36AM T7.00009 Large Molecules Reveal a Linear Length Scaling for Double Photoionization

RALF WEHLITZ, TIM HARTMAN, PAVLE JURANIĆ, SRC, Univ. of Wisconsin - Madison, KELLY COLLINS, Univ. of Evansville, BETHANY REILLY, Univ. of Wisconsin - Madison, NARAYANA APPATHURAI, SRC, Univ. of Wisconsin - Madison — We have determined the ratio of doubly-charged to all singly-charged parent ions of partially deuterated benzene, naphthalene, anthracene, and pentacene up to 30 eV above their double-ionization thresholds. These ratios increase linearly with the length of the molecule. This means that the general structure (here: the length) of a molecule can have a significant influence on the ratio and that the origin of the two emitted electrons can be as far apart as the length of the molecule. Moreover and quite surprisingly, the overall energy dependences of the molecules’ ratios are very similar to that of He and the structure of these molecules does not affect the shape of the energy dependence of the ratio. We interpret this as direct evidence for the validity of the knock-out model even for large molecules and not just for atoms. We want to mention that the increase of the molecules’ ratios may not only be valid for molecules of increasing lengths but also for molecules that increase in size in two dimensions such as pyrene and coronene.

1The SRC was supported by NSF Grant No. DMR-0537588.
2Present address: Paul Scherrer Institute, Switzerland

9:48AM T7.00010 Strong field Molecular ionization and control viewed with Velocity Map Imaging

DOMINIK GEISSLER, SUNY Stony Brook, TAMÁS ROZGONVY, Chemical Research Center of the Hungarian Academy of Sciences, JESÚS GONZÁLEZ-VÁZQUEZ, Instituto de Química Física Rocasolano, CSC, PÉTER SANDOR, SUNY Stony Brook, LETICIA GONZÁLEZ, PHILIPP MARQUE-TAND, Institute of Theoretical Chemistry, University of Vienna, THOMAS C. WEINACHT, SUNY Stony Brook — We employ velocity map imaging of electrons and fragment ions to characterize molecular wave packets after interaction with a strong field ultrashort laser pulse (central wavelength 780nm). Our measurements reveal superpositions of electronic states created by strong field ionization. They also demonstrate how dynamic Stark shifts can alter the PESs for a given electronic state sufficiently to change the propagation of a vibrational wavepacket. In the experiment, we prepare the molecules in an excited state and apply a strong IR pulse, whose basic parameters (intensity, time delay and chirp) are systematically varied. The results of the measurements are compared with ab-initio structure and dynamics calculations in order to verify our interpretation.

Friday, June 8, 2012 10:30AM - 12:30PM –
Session U1 Hot Topics Grand Ballroom BCD - Chair: David Schultz, University of North Texas
PHIL RICHERME, Bates College — Long-lived electronic and nuclear spin states have made the nitrogen-vacancy (NV) defect in diamond a leading candidate for quantum information processing in the solid state. Multi-qubit quantum registers formed by single defects and nearby nuclear spins can currently be controlled and detected with high fidelity. Nevertheless, development of coherent connections between distant NVs remains an outstanding challenge. One advantage to working with solid-state defects is the opportunity to integrate them with microfabricated mechanical, electronic, or optical devices; in principle, such devices could mediate interactions between registers, turning them into nodes within a larger quantum network. In the last few months, several experiments have made key steps toward realizing a coherent quantum interface between individual NV centers using a mechanical quantum bus [1] or optical channels [2,3]. This talk will explore the current state of the art, and report on recent observation of two photon quantum interference between different gate-tunable defect centers [2]. These results pave the way towards measurement-based entanglement between remote NV centers and the realization of quantum networks with solid-state spins.


11:00AM U1.00002 Frequency combs and precision spectroscopy in the extreme ultraviolet
ARMAN CINGÖZ1, JILA and University of Colorado Boulder — Development of the optical frequency comb has revolutionized optical metrology and precision spectroscopy due to its ability to provide a precise link between microwave and optical frequencies. A novel application that aims to extend the precision and accuracy obtained to the extreme ultraviolet (XUV) is the generation of XUV frequency combs via intracavity high harmonic generation (HHG). Recently, we have been able to generate > 200 µW average power per harmonic and demonstrate the comb structure of the high harmonics by resolving atomic argon and neon lines at 82 and 63 nm, respectively [1]. The argon transition linewidth of 10 MHz, limited by residual Doppler broadening, is unprecedented in this spectral region and places a stringent upper limit on the linewidth of individual comb teeth. To overcome this limitation, we have constructed two independent intracavity HHG sources to study the phase coherence directly via the heterodyne beats between them. With these developments, ultrahigh precision spectroscopy in the XUV is within grasp and has a wide range of applications that include tests of bound state quantum electrodynamics, development of nuclear clocks, and searches for variations of fundamental constants using the enhanced sensitivity of highly charged ions.

[1] In collaboration with Tom Allison, Dylan Yost, Craig Benko, Jun Ye (JILA & Univ. of Colo. Boulder), Axel Ruehl (IMRA America Inc. and Inst. for Lasers, Life & Biophotonics, Vrije Universiteit Amsterdam), Martin Ferrann, Ingmar Hartl (IMR America, Inc.)

11:30AM U1.00003 Spins and photons: connecting quantum registers in diamond
LILY CHILDEESS, Bates College — Three recent advances in antimatter physics show significant progress towards precision tests of fundamental symmetries.

The first and primary focus of this talk is ATRAP’s observation of five simultaneously trapped antihydrogen atoms per trial, confined for long enough to ensure that they are in their ground state. Large numbers of simultaneously trapped atoms are crucial if laser cooling and spectroscopy of antihydrogen at high levels of precision are to be achieved. Fundamental to this result is the careful control and characterization of the geometry and temperature of the large-number space in which the atoms are trapped. A second advance, by the ALPHA collaboration, is a demonstration that smaller numbers of simultaneously trapped antihydrogen atoms can be ejected from a place of the photons in a good-cavity laser. The system can operate with as few as 0.2 intracavity photons and with an excited state decay linewidth < 1 Hz. This model system demonstrates key physics for future active optical clocks (similar to masers) that may achieve frequency linewidths approaching 1 mHz due to greatly reduced sensitivity to thermal and environmental mirror noise.

JAMES K. THOMPSON2, JILA, NIST, and Dept. of Physics, University of Colorado at Boulder — We have demonstrated the quasi-continuous operation of a Raman laser that operates deep into the superradiant or bad-cavity regime. In this laser, laser-cooled Rb atoms act as the flywheel for phase information, in place of the photons in a good-cavity laser.

This system can operate with as few as 0.2 intracavity photons and with an excited state decay linewidth < 1 Hz. This model system demonstrates key physics for future active optical clocks (similar to masers) that may achieve frequency linewidths approaching 1 mHz due to greatly reduced sensitivity to thermal and environmental mirror noise.

1This work was supported by NSF PFC, NIST, ARO, DARPA QuASAR, NSF GRF, and A*STAR.

2In collaboration with: Justin G. Bohnet, Zilong Chen, Joshua M. Weiner, Dominic Meiser, Murray J. Holland. JILA, NIST, and Dept. of Physics, University of Colorado at Boulder.

IHAA RICHERME, Bates College — Long-lived electronic and nuclear spin states have made the nitrogen-vacancy (NV) defect in diamond a leading candidate for quantum information processing in the solid state. Multi-qubit quantum registers formed by single defects and nearby nuclear spins can currently be controlled and detected with high fidelity. Nevertheless, development of coherent connections between distant NVs remains an outstanding challenge. One advantage to working with solid-state defects is the opportunity to integrate them with microfabricated mechanical, electronic, or optical devices; in principle, such devices could mediate interactions between registers, turning them into nodes within a larger quantum network. In the last few months, several experiments have made key steps toward realizing a coherent quantum interface between individual NV centers using a mechanical quantum bus [1] or optical channels [2,3]. This talk will explore the current state of the art, and report on recent observation of two photon quantum interference between different gate-tunable defect centers [2]. These results pave the way towards measurement-based entanglement between remote NV centers and the realization of quantum networks with solid-state spins.


12:00PM U1.00004 Antimatter Advances Include Trapped Antihydrogen in Its Ground State
PHIL RICHERME, Harvard University — Three recent advances in antimatter physics show significant progress towards precision tests of fundamental symmetries.

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1This work was supported by the NSF and the AFOSR.

2In collaboration with: Justin G. Bohnet, Zilong Chen, Joshua M. Weiner, Dominic Meiser, Murray J. Holland. JILA, NIST, and Dept. of Physics, University of Colorado at Boulder.

10:30AM U2.00001 Quantum Monte Carlo simulations and thermometry in ultracold quantum gases
MATTHIAS TROYER, ETH Zurich — Modern quantum Monte Carlo algorithms allow accurate simulations of both bosons and fermions in optical lattice at the temperatures relevant for cold atomic gases in optical lattices. These simulations allow quantitative validation of optical lattice experiments, and to use comparison to simulations for thermometry. I will review the state of the art of QMC algorithms for bosons and fermions, and present an overview of results obtained that are relevant for optical lattice experiments, including full thermodynamic data and the equation of state for the fermionic and bosonic Hubbard model. I will then focus on a proposal for universal thermometry in bosonic quantum gases [Qi Zhou and Tin-Lun Ho, PRL 106, 225301 (2011)], based on a generalized fluctuation-dissipation theorem. By applying a their scheme to our QMC results I will show that a variant of their proposal does indeed provide a reliable method for thermometry in quantum gases.

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Friday, June 8, 2012 10:30AM - 12:18PM –
Session U2 Focus Session: Universal Thermodynamics and Criticality
Grand Ballroom GF - Chair: Nathan Gemelle, Pennsylvania State University
11:00AM U2.00002 Quantum Criticality and Dynamics in Two-dimensional Bose Gases, XIBO ZHANG, LI-CHUNG HA, The University of Chicago, CHEN-LUNG HUNG, California Institute of Technology, SHIH-KUANG TUNG, CHENG CHIN, The University of Chicago — Quantum criticality emerges when a many-body system is in the proximity of a continuous phase transition driven by quantum fluctuations. In the quantum critical regime, exotic, yet universal properties are anticipated; ultracold atoms provide a clean system to test these predictions. We report the observation of quantum criticality with two-dimensional (2D) Bose gases in optical lattices [1]. Based on this idea, we observe scaling behavior of the equation of state at low temperatures, locate the quantum critical point, and constrain the critical exponents ($z = 2.2^{+0.5}_{-0.7}$ and $\nu = 0.52^{+0.10}_{-0.09}$). We observe a finite critical entropy per particle ($\sim 2k_B$) carrying a weak dependence on the atomic interaction strength. We also study the dynamics of 2D gases by measuring the evolution of the static structure factor after quenching the atomic interaction near a Feshbach resonance. The high-resolution imaging system allows us to resolve the correlation of the density fluctuations with a spatial frequency up to $3.5 \mu m^{-1}$. Our experiment provides an excellent test ground to explore quantum criticality and critical dynamics with ultracold atoms.

[1] This work was supported by IFRAF, ERC and Institut Universitaire de France.

11:12AM U2.00003 Equation of state of strongly interacting fermions, FREDERIC CHEVY, Ecole Normale Superieure — Based on very general principles, Thermodynamics provides powerful tools to characterize the macroscopic properties of any physical system. Even though its origin can be traced back the 19th century’s industrial revolution, I will show how this theory provided the framework and the key ingredients leading to a precise quantitative understanding of the properties of the strongly correlated Fermi gases that were recently obtained thanks to the progress in the manipulation of ultracold atoms.

11:42AM U2.00004 On a scale-invariant Fermi gas in a time-dependent harmonic potential, SERGEJ MOROZ, University of Washington — We investigate a scale-invariant two-component Fermi gas in a time-dependent isotropic harmonic potential. The exact time evolution of density distribution in position space in any spatial dimension is obtained. Two experimentally relevant examples— an abrupt change and a periodic modulation of a trapping frequency are solved. Consequences for experiments with ultracold quantum gases such as the excitation of a tower of undamped breathing modes and the stabilization of an antitrapped system by an AC magnetic field are discussed. Small deviations from the scale invariance and isotropy of the confinement are also considered.

11:54AM U2.00005 Universal relations for Fermi gases in arbitrary dimension, MANUEL VALIENTE, NIKOLAJ T. ZINNER, KLAUS MOLMER, Department of Physics & Astronomy, Aarhus University — We present universal relations for Fermi gases with pairwise renormalizable contact interactions in arbitrary dimensions. The derivation of these relations is given by using the explicit form of a class of generalized functions – Tan’s selectors – in the momentum representation. These selectors implement the short-distance boundary conditions in a straightforward manner and leads to simple derivation of the universal relations.

12:06PM U2.00006 Thermodynamic properties of the SU(2N) ultra-cold fermions in optical lattices, HSIANG-HSUJAN HUNG, ZI CAI, Department of Physics, University of California, LEI WANG, Institute for Theoretical Physics, ETH, DONG ZHENG, Department of Physics, Tsinghua University, CONGJUN WU, Department of Physics, University of California — We investigate the thermodynamic properties of a half-filled SU(2N) Fermi-Hubbard model in the two-dimensional square lattice using the determinantal quantum Monte Carlo simulation, which is free of the fermion "sign problem". The large number of hyperfine-spin components enhances spin fluctuations, which facilitates the Pomeranchuk cooling to temperatures comparable to the superexchange energy scale at the case of SU(6). Various quantities including entropy, charge fluctuation, and spin correlations have been calculated.

Friday, June 8, 2012 10:30AM - 12:18PM — Session U3 Interactions Involving Antimatter or Charge Transfer Grand Ballroom E - Chair: Francis Robicheaux, Auburn University

10:30AM U3.00001 Efficient Production of Rydberg Positronium, TOMU HISAKADO, DAVID CASSIDY, HARRY TOM, ALLEN MILLS, UC Riverside, Department of Physics and Astronomy, UC RIVERSIDE DEPARTMENT OF PHYSICS AND ASTRONOMY TEAM — We demonstrated the efficient production of Rydberg Positronium atoms using a two-step incoherent laser excitation process. The two-step process occurs first to the 23P state and then to the quantum numbers ranging from 10 to 25. We found a 90% efficiency going from the 23P state to the Rydberg levels and an overall conversion efficiency of 25% of the production of Rydberg atoms. This high efficiency is due to the overlap of the laser bandwidth with the Doppler broadened width of the 1s-2p transition and the suppression of the stimulated emission back to the 2P states, due to the intermixing of the Rydberg state Stark sublevels. By demonstrating the production of long lived Rydberg Ps atoms in a high magnetic field may make it possible to perform gravitational measurements of free falling positronium atoms.

10:42AM U3.00002 Towards a hyperspherical description of positronium-positronium scattering, JAVIER VON STECHER, CHRIS H. GREENE, Department of Physics and JILA, University of Colorado, Boulder, CO 80309-0440 — The interest in the scattering properties of the positronium (Ps) has grown with the possibility of creating a Bose-Einstein condensate of matter-antimatter. Such an experimental realization would not only permit an exploration of quantum effects at macroscopic temperatures, but it would also contribute to our understanding of the relationship between the Ps molecule and more conventional molecules like H2. A deep understanding of positronium’s collisional properties is crucial for cooling techniques and for the realization of a Bose-Einstein condensate. A hyperspherical analysis of this four-body system with two electrons and two positrons allow us not only to benchmark calculations of the Ps-Ps scattering length which have been previously studied (see e.g. Ref. [1]) but also to analyze recombination processes such as Ps+e− → Ps+Ps or Ps− + e+, etc... We extend previous implementations of the correlated Gaussian hyperspherical method [2] to describe four-body systems with Coulomb interactions. The results from this hyperspherical analysis are compared with previous studies and correlated Gaussian calculations.


This work is supported in part by NSF
10:54AM U3.00003 Low-Energy Positron Scattering from $H_2$\(^+\) \cite{1}, J.R. MACHACEK\(^\dagger\), E. ANDERSON, C. MAKOCHKEKWANA, Centre for Antimatter-Matter Studies, D. MUELLER, University of North Texas, J.P. SULLIVAN, S.J. BUCKMAN, Centre for Antimatter-Matter Studies — We present low-energy positron scattering measurements from molecular hydrogen. Our measurements were conducted at the high-resolution, low-energy positron beamline at the Australian National University \cite{1}. The energy width of the positron beam was typically 60 meV. We present results for the positron scattering from $H_2$ from 1 to 200 eV for the total and positronium formation cross sections as well as total elastic and elastic differential cross sections. Comparison will be made with previous results, in particular recent results of the Trento group \cite{2}, along with a discussion of the experimental advantages and limitations of present techniques \cite{3}. The greatest discrepancy between the available experimental and theoretical data sets lies at energies below the positronium formation threshold. A plausible explanation for these differences will be presented.

\begin{thebibliography}{9}
\bibitem{2} A. Zecca \textit{et al.}, Phys. Rev. A \textbf{80}, 032702 (2009)
\end{thebibliography}

3This work is supported by the Australian Research Council through its Centre of Excellence Program.

11:06AM U3.00004 Low-energy S- and P-wave Positronium-Hydrogen Collisions\(^\dagger\), DENTON WOODS, S.J. WARD, University of North Texas, P. VAN REETH, University College London — Positronium-atom scattering is of experimental interest. We have investigated low-energy positronium-hydrogen scattering, a fundamental four-body Coulomb process. We computed the S- and P-wave phase shifts using a number of variants of the Kohn variational method. For the S-wave, we implemented various techniques to overcome linear dependence problems. Our results compare favorably with earlier Kohn variational calculations \cite{1}. We determined the S-wave scattering length and effective range using a quantum defect theory for the van der Waals interaction \cite{2}.

\begin{thebibliography}{9}
\end{thebibliography}

1S. J. W. acknowledges support from NSF under grant no. PHYS. 968638.

11:18AM U3.00005 Few Body Quantum Dynamics of high-Z Ions studied at the Future Relativistic HESR Storage Ring, SIEGBERT HAGMANN, THOMAS STOEHLKER, YURI LITVINOV, CHRISTOPHOR KOZHUHAROV, PIERRE-MICHEL HILLENBRAND, MICHAEL LESTINSKY, GSI Darmstadt, DIETER SCHNEIDER, Lawrence Livermore National Laboratory, KURT STIEBING, Inst. Fuer Kernphysik Univ. Frankfurt, GSI DARMSTADT TEAM, INST F. KERNPHYSIK UNIV FRANKFURT TEAM, HELMHOLTZ INSTITUT JENA TEAM, PHYSIKAL. INSTITUT UNIV. JENA TEAM, LAWRENCE LIVERMORE NATIONAL LABORATORY TEAM — At the FAIR facility for antiprotons and ion research the high energy storage ring HESR, originally conceived for experiments using antiprotons, will be configured to also provide highly-charged heavy ions up to beam energies corresponding to $\gamma=5$. This opens a wealth of opportunities for in-ring atomic physics experiments on few-body quantum dynamics ranging from e.g. dynamics of various $e^+e^-\rightarrow e^+e^-$ pair creation processes to quasi-photoionisation of inner shells of the highest-Z Ions. We will discuss various in-ring spectrometers permitting characterization of the pertaining fundamental processes in a kinematically complete fashion.

11:30AM U3.00006 Charge exchange and spectroscopy with isolated highly-charged ions, NICHOLAS D. GUISE, National Institute of Standards and Technology (NIST), SAMUEL M. BREWER, University of Maryland, JOSEPH N. TAN, NIST — Compact ion traps can be useful in facilitating the study and manipulation of highly charged ions isolated in a controlled environment. Various ions of interest, including bare nuclei, are produced in the NIST electron beam ion trap (EBIT), extracted through a beamline that selects a single charge/mass species, then captured in a compact permanent magnet Penning trap or RF trap. The isolated ions are detected optically or by ejection to a fast time-of-flight microchannel plate detector in this room-temperature apparatus, demonstrated ion storage lifetimes exceed one second for species including Ne$^{10+}$ and Ar$^{13+}$, sufficiently long to measure certain metastable lifetimes via fluorescence detection \cite{1}, and to observe charge-exchange processes between trapped ions and residual background gas. A beam of Rydberg rubidium atoms, under development, may enable production of hydrogenlike ions in circular Rydberg states, via charge exchange with trapped bare nuclei; such one-electron ions are attractive for tests of theory and fundamental metrology \cite{2}. Other applications include spectroscopic studies of trapped highly charged ions relevant to atomic physics, astrophysics, and plasmas.

\begin{thebibliography}{9}
\bibitem{1} J.N. Tan, S.M. Brewer, and N.D. Guise, at this meeting (poster).
\bibitem{2} S.M. Brewer, N.D. Guise, and J.N. Tan, at this meeting.
\end{thebibliography}

11:42AM U3.00007 Vibrationally Resolved NonDissociative Charge Transfer in Collisions between Hydrogen or Deuterium Molecules and Atomic or Molecular Ions\(^\dagger\), V.M. ANDRIANARIJAOA, J.G. KING, M.F. MARTIN, Department of Physics, Pacific Union College, Angwin CA 94508, USA, X. URBAIN, Université Catholique de Louvain, Institute of Condensed Matter and Nanosciences, Chemin du Cyclotron 2, B-1348 Louvain-la-Neuve, Belgium — Using a 3-D imaging technique, the vibrational distributions of slow $H_2^+$ or $D_2^+$ produced by charge transfer (CT) between an $H_2$ or $D_2$ target and various fast ions ($H^+$, $D^+$, $H_2^+$, $D_2^+$, He$^+$, and H$^+$) were measured from 10 eV to few keV energies in the laboratory frame. The atomic/molecular ions are extracted from a duoplasmatron ion source, accelerated and decelerated to enter the collision cell hosting neutral molecules from an effusive jet. The CT daughter molecular ions are extracted sideways and accelerated to 2 keV before crossing an effusive potassium jet to undergo resonant dissociative CT. The positions and flight time difference of the two resulting particles give access to the vibrational distribution of the CT products. At 50 eV and above, our results on the $(H_2, H^+)$ system benchmark state-to-state calculations \cite{1}. At lower energies, deviations from theory suggest that vibrational modes start to play an important role in the CT dynamics.

\begin{thebibliography}{9}
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1Research supported by the Fund for Scientific Research – FNRS through IISN Grant No. 4.4504.10, and the National Science Foundation through Grant No. PHY-106887.
11:54AM U3.00008 Observing forbidden radiative decay of highly charged ions in a compact Penning trap, SAMUEL M. BREWER, University of Maryland at College Park, NICHOLAS D. GUISE, JOSEPH N. TAN, National Institute of Standards and Technology — We report observations of radiative decay from metastable states of highly charged ions captured in a newly-developed compact Penning trap. Ions of interest are created in the NIST electron beam ion trap (EBIT), extracted in an ion beamline, and captured in a compact Penning trap built in a novel unitary architecture to facilitate collection of photons emitted by stored ions. As an example, Ar$^{13+}$ ions are captured in one of the two fine structure levels forming the lowest lying states, allowing us to monitor the fluorescence (blue light) of the spin-flipping (M1) decay to the ground state. We present recent results from the newly deployed ion capture apparatus and briefly discuss previous in-EBIT experiments as well as an earlier study involving ion capture in an electrostatic ion trap. Our results illustrate the potential of unitary Penning traps for a variety of studies including experiments to produce hydrogen-like ions for spectroscopic tests of QED.

2. N.D. Guise, et. al., “Charge Exchange and spectroscopy with isolated highly charged ions,” at this meeting.

12:06PM U3.00009 Si$^{3+}$ +H collisions: role of rotational couplings, D.C. JOSEPH, B.C. SAHA, Department of Physics, Florida A&M University, Tallahassee, FL-32307 — State selective charge exchange cross sections are calculated using both the quantum and the semi-classical molecular orbital close coupling approaches in the adiabatic representation. In addition to radial coupling, all angular couplings are also incorporated in our close coupling calculations. The multi-reference single- and double-excitation configuration interaction (MRD-CI) method is employed to describe the adiabatic electronic states of (SiH)$^{3+}$ system. Details of our findings will be reported at the conference.


1Supported by NSF CREST Project.

Friday, June 8, 2012 10:30AM - 12:30PM — Session U4 Atomic and Molecular Structure and Spectroscopy II Garden 1-2 - Chair: Steve Lundeen, Colorado State University

10:30AM U4.00001 ABSTRACT MOVED TO U1.00002 —

10:42AM U4.00002 Calculation of Ionization in Direct Frequency Comb Spectroscopy, BACHANA LOMSAZDE, CHARLES FEHRENBACK, BRETT DEPAOLA, Kansas State University — Direct Frequency Comb Spectroscopy (DFCS) is currently the most precise technique known for measuring the structure of atomic and molecular systems. Usually in DFCS one measures the fluorescence signal coming from the excited states of the target system as a function of the laser’s repetition frequency ($f_{rep}$) or offset ($f_{off}$) frequency. In recent years this process also has been thoroughly modeled theoretically. Although subsequent ionization of the excited states by the comb laser is possible, it has not been considered, either in theory or in experiment. The goal for this work was to expand existing computer code to include photoionization. Our calculations for atomic Rb show that the ion yield is comparable to fluorescence. Furthermore, the ionization spectrum, as a function of $f_{rep}$ or $f_{off}$, replicates the structure of the corresponding fluorescence spectrum. Experimentally, this could be useful because ion detection efficiency is generally very high. We have constructed an apparatus to test the theoretical predictions. We show the results of our calculations and our measurements.

10:54AM U4.00003 Developments in Cavity-Enhanced Direct Frequency Comb Spectroscopy (CE-DFCS), BRYCE BJORK, ALEKSANDRA FOLTYNOWICZ-MATYBA, ADAM FLEISHER, PIOTR MASŁOWSKI, JILA, University of Colorado, JUN YE, JILA, National Institute of Standards and Technology and University of Colorado — We achieve a quantum-noise-limited absorption sensitivity of $1.7 \times 10^{-12}$ cm$^{-1}$ per spectral element at 400 s of acquisition time using the cavity-enhanced direct frequency comb spectroscopy (CE-DFCS) technique in the mid-infrared. A frequency comb is locked to a high-finesse optical cavity and spectra are recorded using a fast-scanning Fourier transform spectrometer with an ultralow-noise autobalancing detector. In this talk, we will discuss our recent technical achievements and detailed understandings of the cavity-enhanced technique and mid-infrared detection methods. In addition, we will present trace gas detection as an application of the technique.

11:06AM U4.00004 Hyperfine Interactions and Electric Dipole of Cs 11s by Using Electromagnetically Induced Transparency1, CHIN-CHUN TSAI, ZONG-SYUN HE, JYH-HUNG TSAI, MING-TSUNG LEE, YUNG-YUNG CHANG, Department of Physics, National Cheng-Kung University, Tainan, Taiwan, THOU-JEN WHANG, Department of Chemistry, National Cheng-Kung University, Tainan, Taiwan — Using electromagnetically induced transparency, the hyperfine structure of the 11s state of cesium was measured and analyzed. To improve the accuracy of frequency measurement, a reference probe beam produced from an acousto-optical modulator overlapped with the original probe beam was served as a frequency marker. The hyperfine magnetic dipole constant A of Cs 11s can be derived from the splitting intervals of the observed spectrum. The result is $A = 38.83 \pm 0.26$ MHz. A numerical simulation based on solving the steady state density matrix solution involving dressed-state atom-photon interaction picture, multi-intermediate levels and optical pumping can quantitatively fit the experimental data.

1This work is supported by the National Science Council, Taiwan.

11:18AM U4.00005 Detecting the single photon recoil using trapped ions, CORNELIUS HEMPEL, BENJAMIN P. LANYON, PETAR JURCEVIC, FLORIAN ZAEHRINGER, Institute for Quantum Optics and Quantum Information (IQOQI), Innsbruck & University of Innsbruck, Austria, RENE GERRITSMA, Institute of Physics, University of Mainz, RAINER BLATT, CHRISTIAN F. ROOS, Institute for Quantum Optics and Quantum Information (IQOQI), Innsbruck & University of Innsbruck, Austria — I will report on our current work to measure the recoil due to a single photon scattering from a single ion. For this experiment two ions are loaded into a linear ion trap: one well characterized “measurement” ion and one “spectroscopy ion” on which the photon scattering event is to be detected. The photon recoil energy excites the common vibrational mode shared by both ions. In order to detect this extremely small vibration, we make use of a very sensitive highly non-classical motional state. Our technique could have interesting applications in performing spectroscopy of atoms or molecules at the single photon / single atom level.

1We acknowledge support by the Austrian Science Fund (FWF), the Institut fuer Quanteninformation GmbH, and by the European Commission via the integrated project AQUTE and a Marie Curie International Incoming Fellowship.
11:30AM U4.00006 Subnatural spectroscopy by two-photon frequency modulation, LEI FENG, PENGXIONG LI, Fudan University, LIANG JIANG, California Institute of Technology, YANHONG XIAO, Fudan University — We demonstrate a two-photon frequency-modulation subnatural spectroscopy technique. The two levels for the target resonance are both resonantly coupled to an auxiliary level by two phase coherent lasers under common phase modulation. Cross correlation in the converted amplitude modulation of the two lasers was measured versus detuning. Linewidth thirty times narrower than the measured natural width (zero laser power width) of the target resonance was experimentally achieved using Coherent- Population- Trapping as a proof-of-principle system. Dependence of linewidth on laser power, modulation depth and frequency was investigated. Experimental results agree well with theoretical models. This technique is generally applicable to many systems for precision spectroscopy, metrology and imaging.

11:42AM U4.00007 Sub-femt-O-Tesla Scalar Atomic Magnetometer with Spin-squeezing1, DONG SHENG, SHU GUANG LI, NEZIH DURAL, MICHAEL ROMALIS, Physics Department, Princeton University — Atomic shot noise sets the fundamental limit on precision of atomic frequency measurements. Spin-squeezing techniques can reduce long-term atomic shot noise for systems with non-linear spin-relaxation processes [1]. Magnetometers using dense hot alkali-metal vapors are naturally limited by such non-linear relaxation due to spin-exchange collisions. We have developed a scalar atomic magnetometer utilizing a multi-pass atomic cell [2] to interact with $^{103}$ atoms with an optical density of 5000. By operating the magnetometer in a pulsed mode with high initial spin polarization and two probe measurement pulses, we have realized magnetic field sensitivity of 0.5 fT/$\sqrt{Hz}$, already more than an order of magnitude better than previous state-of-the-art for scalar atomic magnetometers. We are continuing to refine this system to realize an improvement in the long-term sensitivity from spin-squeezing measurements beyond the present magnetic field sensitivity records.

1 Work supported by DARPA.

11:54AM U4.00008 Excitation energies, radiative and autoionization rates, dielectronic satellite lines, and dielectronic recombination rates for excited states of Yb-like W$^{1+}$, P. BEIERSDORFER, Lawrence Livermore National Laboratory, U.I. SAFRONOVA, A.S. SAFRONOVA, University of Nevada, Reno — Energy levels, radiative transition probabilities, and autoionization rates for [Cd]4$^l$14$^p$6$^d$5$^l$nl, [Cd]4$^l$14$^p$6$^d$5$^l$nl, [Cd]4$^l$14$^p$6$^d$5$^l$nl, [Cd]4$^l$14$^p$6$^d$5$^l$nl, and [Cd]4$^l$14$^p$6$^d$5$^l$nl (l' = d, f, g, l'' = s, p, d, f, g, n = 5 – 7) states of Yb-like tungsten (W$^{1+}$) are calculated using the RMBPT, HULLAC, and COWAN codes. Branching ratios relative to the [Cd]4$^l$14$^p$6$^d$5$^l$nl, [Cd]4$^l$14$^p$6$^d$5$^l$nl, and [Cd]4$^l$14$^p$6$^d$5$^l$nl thresholds in Tm-like tungsten and intensity factors are calculated for satellite lines, and dielectronic recombination (DR) rate coefficients are determined for the singly excited, as well as non-autoionizing core-excited states in Yb-like tungsten. Contributions from the autoionization doubly excited and core-excited states (with n up to 100), which are particular important for calculating total DR rates, are estimated. Synthetic dielectronic satellite spectra from Yb-like W are simulated in a broad spectral range from 200 to 1400 Å. These calculations provide recommended values critically evaluated for their accuracy for a number of W$^{1+}$ properties useful for a variety of applications including for fusion applications.

2 This work was supported under DOE in part by the OFES grant DE-FG02-08ER55491 and in part under the NNSA CA DE-FC52-06NA27564. Work at the LLNL was performed under auspices of the DOE under contract DE-AC5207NA2344.

12:06PM U4.00009 Testing the accuracy of the coupled-cluster method for trivalent atoms1, HEMAN GHARIBNEJAD, ANDREI DEREVIANKO, University of Nevada-Reno — We use coupled-cluster method for computation of electron correlation energies, hyperfine constants and dipole matrix elements of some of the low-lying states of atomic boron. The calculations are done with converging techniques and include up to three excitations. The goal is to establish the accuracy of the couple-cluster method for a system of three valence electrons so that it can be extended to compute the structure of heavier atoms in the same atomic group such as thallium. High precision computations on heavy atoms will in turn lead to more stringent constraints on new physics beyond the Standard Model, derived from atomic parity violation.

3 This work was supported in part by the NSF.

12:18PM U4.00010 Relativistic Pseudopotential Followed by Restoration Method for Studying Heavy-Atom Systems1, ALEXANDER PETROV, B.P.Konstantinov Petersburg Nuclear Physics Institute; Department of Physics, St. Petersburg State University, LEONID SKRIPNIKOV, NIKOLAY MOSYAGIN, ANATOLY TITOV, B.P. Konstantinov Petersburg Nuclear Physics Institute — Precise all-electron four-component treatment of molecules with heavy elements is yet rather consuming. In turn, the relativistic pseudopotential (RPP) method is the most straightforward way now to study efficiently “valence” (optic, electric, chemical etc.) properties of rather complicated systems. However, the valence molecular spinors are usually smoothed in atomic cores. Therefore, direct calculation of electronic densities near heavy nuclei within the RPP approach is impossible. In the report, an approach based on the RPP method and one-center core-restoration technique [1] developed by the authors for such studies is discussed. It efficiency is illustrated in benchmark-to-database calculations of magnetic—dipole and electric quadrupole hyperfine—structure constants, as well as the space parity (P) and time-reversal symmetry (T) nonconservation effects in polar heavy-atom molecules, including HIF, WC, PbF, PbO, YbF, ThO and some other candidates which are studied now as promising molecules for the experimental search of the electron electric dipole moment (eEDM).


3 This work is supported by the RFBR Grant No. 10–03–00727a

Friday, June 8, 2012 10:30AM - 12:30PM –
Session U5 Matter-Wave Interferometry II and Cold Plasmas
Garden 3 - Chair: Scott Bergeson, Brigham Young University

10:30AM U5.00001 Using a lens for matter waves in an atom interferometer, RAISA TRUBKO, IVAN HROMADA, WILLIAM HOLMGREN, ALEXANDER CRONIN, University of Arizona — We demonstrate the use of a lens for matter waves that increased our interference fringe contrast from 16% to 24%. To create our lens, we used a static electric field gradient inside our three nanograting Mach-Zehnder atom interferometer. We discovered that our lens (f = -500m) can compensate for misalignments, such as imperfect grating period. We explore how the (de)focusing effect can influence our precision measurements of atomic polarizability, and how such a lens can be useful in other layouts such as a Talbot Lau interferometer. We gratefully acknowledge NSF support for this work.

10:42AM U5.00002 ABSTRACT HAS BEEN MOVED TO P7.00010 —
10:54AM U5.00003 Electric and Magnetic Field Sensing with a Charged Particle Moiré Deflectometer1, ROGER BACH, HERMAN BATELAAN, University of Nebraska-Lincoln, GLEN GRONNIGER, Kansas City Plant, National Secure Manufacturing Center — We report on the realization of a charged particle Moiré deflectometer and its ability to sense electric and magnetic fields. To the best of our knowledge this is the first realization of such a device. Our Moiré deflectometer is based on the classical propagation of an electron beam through a set of three identical nanofabricated gratings. This device can be used with or without collimation of the electron beam. Fields between the gratings shift the beam, resulting in a change in the total transmitted intensity. The scalability and sensitivity will be discussed as well as some of the complications.

1We gratefully appreciate funding for this project from NSF and Honeywell.

11:06AM U5.00004 An ionizing time domain matter-wave interferometer, NADINE DOERRE, PHILIPP HASLINGER, PHILIPP GEYER, JONAS RODEWALD, STEFAN NIMMRICHTER, University of Vienna, Vienna Center of Quantum Science and Technology, Austria. KLAUS HORNBERGER, University of Duisburg-Essen, Germany, MARKUS ARNDT, University of Vienna, Vienna Center of Quantum Science and Technology, Austria — We discuss an optical matter-wave interferometer for clusters and complex molecules that uses absorptive ionization gratings in combination with Talbot-Lau interferometry in the time domain. We show recent results and present the future perspectives of the experiment. In this setup, a particle cloud passes alongside a mirror that reflects three equally timed UV lasers pulses. Electrons are detached from the particles in the antinodes of the formed standing wave gratings via single photon absorption. The created ions are extracted and only neutral particles remain in the interferometer, thus absorptive light gratings for matter waves can be realized. In contrast to material grating setups, this experiment operates in a pulsed mode, which makes the longitudinal motion of the particles negligible. This new kind of interferometer is a universal tool which will on the one hand allow us to explore the wave nature of massive particles, potentially up to a million atomic mass units and more. In combination with deflectometry and spectroscopy on the other hand, it offers the possibility to determine molecular properties, such as polarizabilities, electric and magnetic moments, absorption and ionization cross sections with high precision.

11:18AM U5.00005 Progress Toward a Cold Ion Interferometer, JAMES ARCHIBALD, ERICKSON CHRISTOPHER, JAROM JACKSON, DALLIN DURFEE, Brigham Young University — We describe progress on a cold ion matter-wave interferometer. The ions are generated by laser-cooling strontium and then photo-ionizing the atoms with a two-photon transition to an auto- ionizing state in the continuum. Each ion’s quantum wave will be split and recombined using stimulated Raman transitions between the hyperfine ground states of Sr\textsuperscript{87+}. The interferometer phase will be determined by measuring the fraction of ions exiting in each hyperfine state. We will discuss the theory of operation, experimental methods, and potential applications of the device.

11:30AM U5.00006 Minimizing the effects of disorder-induced heating through electron screening in ultracold plasmas1, MARY LYON, SCOTT BERGESON, Brigham Young University — Strong coupling in plasmas is characterized by the ratio of the nearest-neighbor Coulomb potential energy to the average kinetic energy of the ions. In ultracold plasmas, which are produced by photoionizing laser-cooled atoms, the initial strong coupling parameter is large, due to the low initial temperature of the system. The value of the strong coupling parameter at equilibrium is limited by the relaxation of the ions due to nearest-neighbor interactions, which causes disorder-induced heating (DIH). The effects of DIH can be moderated through electron shielding. Electron screening extends the DIH time and reduces the ion equilibration temperature, thus decreasing the overall effect of DIH on the ion motion. However electron screening also softens the ion-ion interaction strength. The net result is a decrease in the strong coupling of the plasma. We report measurements of this effect due to electron screening and compare these measurements to simulations.

1This project is funded by NSF Grant Number PHY-0969856.

11:42AM U5.00007 The long time dynamics of a molecular ultracold plasma, HOSEIN SADEGHI ESFAHANI, JONATHAN MORMISON, NICOLAS SAQUET, MARKUS SCHULZ-WEILING, EDWARD GRANT, University of British Columbia — Higher-order charged-particle interactions play a significant role in the creation and decay of a molecular ultracold plasma. Describing the forces at work requires the simultaneous consideration of plasma hydrodynamics and coupled collisional rate processes. Accordingly, we present model calculations that account for the effects of inelastic and reactive collisions on the spatial distribution of plasma density and associated hydrodynamic forces. As the plasma shape evolves to depart from a Gaussian sphere, the expanding electron gas exerts non-linear radial force on the ions, which creates a non-uniform radial hydrodynamic velocity field and causes further changes to plasma shape over time. Experimental data and simulation results show good agreement in decay parameters, but differ on expansion rate and thus electron temperature.

11:54AM U5.00008 Ultracold neutral plasma resonant response to few-cycle radiofrequency pulses1, TRUMAN WILSON, WEI-TING CHEN, JACOB ROBERTS, Colorado State University — Ultracold neutral plasmas exhibit a resonant response to applied radiofrequency (RF) fields in the frequency range of several MHz to hundreds of MHz for achievable densities. In typical experiments a single-frequency RF field is applied to the plasma as it expands. When the plasma density drops enough to be in resonance with the applied field, the resonant response is observed as an increase in electron evaporation rate. In contrast, we have conducted measurements where short bursts of RF were applied to the plasma, with pulse durations as short as two cycles studied in detail. We still observed a density-dependent resonant response with these short pulses. The usual description of the increase in evaporation rate being due to local resonant heating of electrons in the plasma is inconsistent with the timescale of the response and other factors. Instead, our results are consistent with a timescale of electron energy transfer from collective motion of the entire electron cloud to electrons in high-energy orbits. In addition to providing a potentially more robust way to measure ultracold neutral plasma densities, these measurements demonstrate the importance of collective motion in the energy transport and evaporation rate in these systems.

1Supported by AFOSR.

12:06PM U5.00009 Creation and interrogation of a correlated molecular plasma, JONATHAN MORRISON, NICOLAS SAQUET, ED GRANT, University of British Columbia — Since the first realization of a correlated molecular plasma formed in a super-sonic beam expansion [1], much work has been devoted to characterizing fundamental parameters of the plasma: the ambipolar expansion rate is driven by electron kinetic energy and has been observed [2] to be lower than ultracold atomic plasmas produced in magneto-optical traps. Molecular dissipation mechanisms present a unique channel for directing energy away from electron kinetic energy. The importance of the entire Rydberg level manifold must be considered to accurately describe these systems [3], increasing the importance of molecular processes both at early, and later instances of the plasma lifetime.

12:18PM U5.00010 Ultracold neutral plasmas at room temperature\textsuperscript{1}\textsuperscript{2}. JOSHUA WILSON, STEPHEN RUPPER, DANIEL THRASHER, NATHAN HEILMANN, SCOTT BERGESON, Brigham Young University — Under certain conditions, the characteristics of ultracold neutral plasmas can be reproduced at room temperature. At high enough density the disorder-induced heating temperature is much greater than room temperature, meaning that the equilibrium ion temperature is determined by the ion density. We produce these plasmas using strong-field ionization of neon atoms in a jet. We have developed an interferometric method for determining the average plasma density as a function of time and observe the plasma expanding on time scales as short as 5 ns. We show that the ultracold neutral plasma expansion model can be used to extract the electron temperature with good reliability.

\textsuperscript{1}This project is funded by NSF Grant Number PHY-0969856

Friday, June 8, 2012 10:30AM - 12:06PM – Session U6 Vortices and Solitons  Garden 4 - Chair: Peter Engels, Washington State University

10:30AM U6.00001 Phase-Dependent Interactions of Bright Matter-Wave Solitons\textsuperscript{1}, PAUL DYKE, SIDONG LEI, RANDALL HULET, Rice University — We investigate the interaction of bright matter-wave solitons with a thin repulsive barrier. The solitons are formed from a Bose-Einstein condensate of \textsuperscript{7}Li atoms confined in quasi-1D by a focused laser beam. We use the broad Feshbach resonance for \textsuperscript{7}Li in the \{1,1\} state to tune the scattering length through zero to small negative values to produce bright matter-wave solitons with atom numbers close to the critical number for collapse. The barrier is generated by a near-resonant cylindrically focused laser beam that perpendicularly bisects the trapping beam. By adjusting the barrier potential, the soliton can either be split in two, transmitted or reflected. We apply a phase imprinting laser beam to one arm of the split soliton to study phase dependent interactions. We also investigate the transmission and reflection probabilities as a function of the strength of non-linear interactions which are tuned via the Feshbach resonance.

\textsuperscript{1}Work supported by the NSF, ONR, Welch Foundation, Texas NHARP, and the US-Israel BSF.

10:42AM U6.00002 Interacting Bright Solitons in Trapped BECs: Mean-Field Theory and Way Beyond\textsuperscript{1}. WILLIAM REINHARDT, University of Washington, Seattle — Bright multi-soliton trains have been experimentally observed in harmonic traps in experiments made especially difficult by the fact that a too-bright soliton (or ground state of an attractive BEC) will self destruct in 3D. These are fascinating systems as, as recently pointed out\textsuperscript{3} usual mean-field descriptions via the NLSE (or GP) equation, will often fail, as many-body effects may play a crucial role. Here we discuss 4 regimes of the statics and dynamics of double-bright-soliton systems by giving an overview of the full energy correlation diagram in a two (non-linear) mode description. 1) Strongly trapped soliton pairs are found to be quite well described by GP, and also via two mode, dynamics, up-holding prior theoretical analysis of existing experiment:\textsuperscript{4} Separated soliton pairs may be: 2) Schrödinger cats; 3) fully fragmented; or, 4) decohering wave packets if followed via two-mode dynamics, using coherent mean-field (GP) initial conditions, and end up producing states of controllable partial entanglement.

\textsuperscript{1}Support by grants from NSF Physics AMO Theory, and NIST, are gratefully acknowledged.
\textsuperscript{2}K. E. Strecker et. al., Nature 417,150 (2002).
\textsuperscript{4}Strecker, op. sit.
\textsuperscript{5}Streltsov, op. sit.

10:54AM U6.00003 Physical and Algebraic Origins of the Reflectionless Property of the Bogoliubov-de-Gennes-sine-Gordon Equation Around a Soliton\textsuperscript{1}. ALBERT ALBERT KAMANZI, ZAIJONG HWANG, MAXIM OLSHANII, University of Massachusetts Boston — We analyze the reflectionless property of the so-called Bogoliubov-de-Gennes-sine-Gordon (BdG-sG) equation—a sine-Gordon equation that has been linearized around a single soliton solution. We demonstrate that the absence of reflection is necessary for the original nonlinear soliton to be transparent for the small breathers. On the other hand, we show that the BdG-sG equation is equivalent to the Pöschl-Teller (PT) potential at transparency, whose transparency, in turn, originates from a SUSY structure of the PT Hamiltonian. Our study provides yet another example of a connection between the Supersymmetric Quantum Mechanics\textsuperscript{2} and integrable partial differential equations, in addition to the known examples of the Lax operators for the Korteweg-de Vries, sine-Gordon, and Nonlinear Schrödinger equations that are shown to have a SUSY structure for some few-solitonic solutions\textsuperscript{3}.

\textsuperscript{1}supported by ONR and NSF
\textsuperscript{2}E. Witten, Nucl. Phys. B 188, 513 (1981)

11:06AM U6.00004 Dynamic Kosterlitz-Thouless transition in 2D Bose mixtures of ultra-cold atoms. LUDWIG MATHEY, Center for Optical Quantum Technologies and Institute for Laser Physics, University of Hamburg, KENNETH GUENTER, JEAN DALIGRAF, Laboratoire Kastler Brossel, Ecole Normale Superieure, ANATOLI POLKOVNIKOV, Boston University — We propose a realistic experiment to demonstrate a dynamic Kosterlitz-Thouless transition in ultra-cold atomic gases in two dimensions. With a numerical implementation of the Truncated Wigner Approximation we simulate the time evolution of several correlation functions, which can be measured via matter wave interference. We demonstrate that the relaxational dynamics is well-described by a real-time renormalization group approach, and argue that these experiments can guide the development of a theoretical framework for the understanding of critical dynamics.

11:18AM U6.00005 Origins of bright soliton transparency to Bogoliubov quasi-particles\textsuperscript{1}. ZAJJONG HWANG, University of Massachusetts Boston, ANDREW KOLLER, University of Massachusetts Boston, University of Colorado Boulder, MAXIM OLSHANII, University of Massachusetts Boston — Bogoliubov quasi-particles can pass through a one-dimensional bright soliton without reflection at all energies\textsuperscript{2}. Reflectionless properties of this kind usually originate from a supersymmetric structure of the corresponding Hamiltonian\textsuperscript{3} However, we give a strong indication that in this case\textsuperscript{4}, the mathematical mechanism enabling full spectrum transparency of a scattering object does not fall into any of the conventional paradigms.

\textsuperscript{1}Supported by NSF, ONR, and IFRAF
\textsuperscript{3}E. Witten, Nucl. Phys. B 188, 513 (1981).
11:30AM U6.00006 Observation of Topologically Stable 2D Skyrmions in an Antiferromagnetic Spinor Bose-Einstein Condensate. This work was supported by National Research Foundation of Korea Grants (Global Ph.D Fellowship, BK Fellowship, No. 2011-0004539, No. 2011-0017527, No. 2011-0001054, and No. WCU23-10045) and Research Settlement Fund for the new faculty of SNU.

10:54AM U6.00007 On the dynamics of bright- and dark-dark solitons in two-component BECs. This procedure may be scaled to larger numbers of pinned vortices and will be useful for generating arbitrary vortex distributions for studies of superfluid dynamics and vortex interactions.

11:42AM U6.00008 Pinning and manipulation of vortex cores in Bose-Einstein condensates. Supported by NSF and DOE SCGF.

Friday, June 8, 2012 10:30AM - 12:30PM
Session U7 Physics with Ultraintense Lasers and Light Sources
Terrace - Chair: Itzik Ben-Ithzak, Kansas State University

10:30AM U7.00001 X-ray resonance fluorescence and Rabi flopping for ultrafast and ultraintense pulses.

10:40AM U7.00002 Femtosecond time-resolved x-ray photoelectron spectroscopy studies of charge transfer dynamics in novel photovoltaic systems.

11:06AM U7.00004 Tracing nuclear wave-packet dynamics in diatomic molecules with XUV pump- and probe- pulses

M. MAGRAKVELIDZE, KSU, O. HERRWERTHER, MPQ, Y.H. JIANG, MPIK, A. RUDENKO, CFEL, M. KURKA, MPIK, L. FOCAR, CFEL, K.U. KÜHNEL, MPIK, M. KUBEL, MPQ, N.G. JOHNSON, KSU, MPQ, C.D. SCHROTER, MPIK, S. DÜSTERER, R. TREUSCH, DESY, M. LEZIUS, MPQ, I. BEN-ITZHAK, KSU, R. MOSHAMMER, MPIK, J. ULLRICH, MPIK, CFEL, M.F. KLING, KSU, MPQ, U. THUMM, KSU — We traced the femtosecond nuclear wave-packet dynamics in ionic states of oxygen and nitrogen diatomic molecules employing 38 eV XUV pump and probe at the Free Electron Laser in Hamburg (FLASH) [2]. The nuclear dynamics is monitored via the detection of coincident ionic fragments using a reaction microscope and a split-mirror setup to generate the pump and probe pulses. By comparing measured kinetic-energy-release (KER) spectra with classical and quantum-mechanical simulations [3], we identified electronic states of the molecular ions that are populated by ionization of the neutral molecule. The comparison of measured KER spectra for specific fragment-charge states allows assessing the relevance of specific dissociation paths.

1Supported by the US DOE and NSF

2Y. H. Jiang et al., PRA 82, 041403(R) (2010).

3I. A. Bocharova et al., PRA 83, 031417 (2011)

11:18AM U7.00005 Laser-generated proton bunches from chirped laser-plasma interaction

BENJAMIN GALOW, Max-Planck-Institute for nuclear physics, Saupfercheckweg 1, 69029 Heidelberg, Germany, YOUSEF SALAMIN, Department of Physics, American University of Sharjah, POB 26666, Sharjah, United Arab Emirates, TATYANA LISEYKINA, Department of Physics, University of Rostock, 18051 Rostock, Germany, ZOLTAN HARMAN, JIAN-XING LI, CHRISTOPH KEITEL, Max-Planck-Institute for nuclear physics, Saupfercheckweg 1, 69029 Heidelberg, Germany — Detailed single- and many-particle calculations are carried out for the acceleration of protons employing linearly-polarized plane-wave and tightly-focused chirped laser pulses of several ten to several hundred femtosecond durations, petawatt peak powers and relativistic peak intensities of the order of $10^{21}-10^{22}$ W/cm$^2$ [1,2]. Analytic and numerical methods of calculation are used in the single-particle cases (in vacuum), and particle-in-cell (pic) simulations (under-dense plasma) are employed in the many-particle investigations, without and with electromagnetic-particle-particle interactions, respectively. Feasibility of generating ultra-intense ($10^{20}$ particles per bunch) and phase-space collimated beams of protons is demonstrated. Interaction of the protons with the quasi-static part of the laser pulse allows the particles to gain sufficient kinetic energy (around 250 MeV) required for such applications as hadron cancer therapy.


11:30AM U7.00006 Controlling Auger decay with electromagnetically induced transparency for x rays

ANTONIO PICON, GILLES DOUMY, STEPHEN SOUTHWORTH, LINDA YOUNG, CHRISTIAN BUTH, Argonne National Laboratory — The emerging x-ray free electron lasers (FELs) such as the Linac Coherent Light Source (LCLS) at SLAC National Accelerator Laboratory can reach very high intensities and ultrashort pulse durations. We analyze how to control Auger decay using a secondary intense near-infrared (NIR) laser with electromagnetically induced transparency for x rays. A three-level $\Lambda$-type model is used, where a core electron is coupled to a Rydberg state by the x rays while the NIR pulse couples the Rydberg states among each other. We use the model to predict the Auger electron spectrum of a neon atom and thus enhance our understanding and control of electron correlations. This work opens up new prospects to study and control the nonlinear interaction of ultraintense and ultrashort x rays with atoms.

1This work is funded by the Office of Basic Energy Sciences, Office of Science, U.S. Department of Energy, under Contract No. DE-AC02-06CH11357.

11:42AM U7.00007 Effect of wave-function localization on the time delay in photoemission from surfaces

UWE THUMM, CHANH-HUA ZHANG, Kansas State University — We investigated streaking time delays in the photoemission from a solid metal surface as a function of the degree of localization of the initial-state wave functions [1]. We consider a 1D slab with lattice constant $a_{\text{latt}}$ consisting of a Mo-Si-B multilayer, where $1/a_{\text{latt}}$ yields the average interatomic distance. The parameter $a_{\text{latt}}$ controls the localization of the electronic eigenfunctions. Small values of $a_{\text{latt}}$ thus control the localization of the electronic eigenfunctions. Large values of $a_{\text{latt}}$ yield lattice eigenfunctions that consist of localized atomic wave functions modulated by a “Bloch-envelope” function, while the eigenfunctions become delocalized for larger values of $a_{\text{latt}}$. From calculated photoemission spectra we deduced a characteristic bimodal shape of the band-averaged photoemission time delay $\tau_{\text{delay}}$ between the photoemission from core and conduction-band levels of a tungsten surface [3].


1Supported by NSF and DOE.

11:54AM U7.00008 Non-linear Compton Scattering in Short Laser Pulses

KATARZYNA KRAJEWSKA, JERZY KAMINSKI, Institute of Theoretical Physics, University of Warsaw — The generation of short X-ray laser pulses attracts a great deal of attention. One of mechanisms to achieve this goal is the non-linear Compton scattering at very high laser powers. The majority of previous works on the non-linear Compton scattering have been devoted to the case when the incident laser field is treated as a monochromatic plane wave. There is, however, recent interest in analyzing the effect of a pulsed laser field on the non-linear Compton scattering [1-4]. We study the process for different durations of the incident laser pulse and compare it with the results for both a plane wave laser field and a laser pulse train.


1This work is supported by the Polish National Science Center, under Grant No. UMO-2011/01/B/ST2/00381.
Theoretical examination of high-order harmonic generation (HHG) by an intense near-infrared (nIR) laser in combination with intense x rays from a free electron laser such as the Linac Coherent Light Source (LCLS) at SLAC. The x rays are tuned above an absorption edge thus causing one-photon ionization of a tightly bound core electron. The liberated core electron is driven by the nIR light through the continuum; when the electric nIR field reverses its direction, the electron may eventually return to the cation leading to its recombination with the core hole and the emission of a high-harmonic photon that is upshifted in energy by the x-ray photon energy. We develop a theory of this x-ray boosted HHG scenario and apply it to 1s electrons of neon atoms. HHG spectra are computed for LCLS pulses which are generated according to the self-amplification of spontaneous emission (SASE) principle. A time-frequency analysis of HHG emission reveals the imprinting of the varying LCLS pulse shapes on the boosted HHG spectrum which may open up prospects for pulse diagnostic. The boosted HHG light is used to generate a single attosecond pulse in the kiloelectronvolt regime by filtering out only the highest HHG photons close to the upshifted cutoff.

C.B. was supported by the U.S. Department of Energy.

Correction of the relativistic factorizable expression (RKJ) for Compton scattering doubly differential cross sections, L.A. LAJOHN, R.H. PRATT, University of Pittsburgh — We have derived simple analytic expressions that can be used to correct the factorizable expression for Compton scattering doubly differential cross sections (DDCS) within the relativistic impulse approximation (RIA). This relativistic factorizable expression, which we refer to as the RKJ approximation, has the nonrelativistic-like form DDCS=KJ, where K is a kinematic factor and J is the Compton profile. The advantage of RKJ is that it allows one to obtain J from observed DDCS in relativistic regimes. However RKJ breaks down for K-shell ionization of moderate to heavy atoms. The error can exceed 25% for heavy atoms such as Uranium. Our correction to RKJ provides accurate Compton profiles at high energy, at least around the maxima, even for the heaviest of atoms. We explain how the formulas for the correction to RKJ can be obtained most conveniently by taking the high incident photon energy \( \omega_i \) limit of the partially integrated form of the full RIA expression for DDCS and why this partially integrated form exhibits the cancellation of much of the relativistic corrections to the RKJ approximation, resulting in simple expressions that yield accurate results. We give the results of tests for the accuracy of the corrected K-shell Compton profiles for heavy atoms.