38th Annual Meeting of the Division of Atomic, Molecular, and Optical Physics
Calgary, Alberta, Canada
http://www.aps.org/meetings/unit/damop/
8:00AM A1.00001 Rabi Prize Talk: The Art of Light-based Precision Measurement. JUN YE, JILA and Physics Department, National Institute of Standards and Technology and University of Colorado — Improvements in spectroscopic resolution have been the driving force behind many scientific and technological breakthroughs over the past century, including the invention of the laser and the realization of ultraslow atoms. Maintaining optical phase coherence is one of the two major ingredients (the other being the control of matter) for this scientific adventure. Lasers with state-of-the-art control can now maintain phase coherence over one second, that is, $10^{15}$ optical waves pass by without losing track of a particular cycle. Translating into distance, such a coherent light wave can traverse the circumference of the Earth 10 times and still interfere with the original light. The recent development of optical frequency combs has allowed this unprecedented optical phase coherence to be established across the entire visible and infrared parts of the electromagnetic spectrum, leading to direct visualization and measurement of light ripples. Working with ultracold atoms prepared in single quantum states, optical spectroscopy and frequency metrology at the highest level of precision and resolution are being accomplished. A new generation of atomic clocks using light has been developed, with anticipated measurement precision reaching 1 part in $10^{18}$. The parallel developments in the time domain have resulted in precise control of the pulse waveform in the sub-femtosecond regime, leading to demonstrations of coherent synthesis of optical pulses and generation of coherent frequency combs in the VUV spectral region. This unified time- and frequency-domain spectroscopic approach allows high-resolution coherent control of quantum dynamics and high-precision measurement of matter structure across a broad spectral width. These developments will have impact to a wide range of scientific problems such as the possible time-variation of fundamental constants and gravitational wave detection, as well as to a variety of technological applications.

References

8:36AM A1.00002 Broida Prize Talk: Stable and Accurate Single-Atom Optical Clocks. JAMES BERGQUIST, APS — The potential for high stability and accuracy of optical clocks based on narrow transitions of single ions has begun to be realized [1-3]. At NIST, we have constructed and are operating two single-ion optical clocks; one based on the $^2S_{1/2} (F = 0) \rightarrow ^2D_{5/2} (F = 2, m_F = 0)$ electric-quadrupole transition ($\lambda = 282$ nm, $\nu = 1.064$ PHz) of a single, laser-cooled $^{199}$Hg$^+$ ion held in a cryogenic rf Paul trap, and one based on the $^1S_{1/2} \rightarrow ^1P_0$ intercombination line ($\lambda = 267$ nm, $\nu = 1.124$ PHz) of a single $^{27}$Al$^+$ ion held in a linear trap [4]. The burden of cooling, state preparation and state detection of the Al$^+$ ion are borne by an auxiliary Be$^+$ ion using quantum logic methods [5]. In a recent comparison of these two standards, we have achieved a relative fractional frequency instability of less than $7 \times 10^{-15} (\tau/\tau)^{1/2}$, reaching $4 \times 10^{-17}$ in 30 000 s. We have also compared the frequency of the Hg$^+$ optical clock to that of the cesium fountain standard NIST-F1, for which we obtained fractional frequency inaccuracies below $10^{-15}$. Repeated measurements of the frequency ratios of the clock transitions of all three standards provide intriguing possibilities for laboratory tests of fundamental physics, such as testing for the “constancy” of the fundamental constants. We will report the results of measurements conducted over the course of five years and discuss the implications of these results as a constraint to present-day temporal variation of the constants [6].

References

9:12AM A1.00003 Nanoelectronics and Plasma Processing — The Next 15 Years and Beyond. MICHAEL A. LIEBERMAN, University of California, Berkeley — The number of transistors per chip has doubled every 2 years since 1959, and this doubling will continue over the next 15 years as transistor sizes shrink. There has been a 25 million-fold decrease in cost for the same performance. There are now as many as 1.5 billion transistors on-chip, with gate lengths as small as 37 nm (120 atoms) and oxide thicknesses as small as 1.5 nm (5 atoms). The smallest working transistor has a 5 nm (17 atoms) gate length, close to the limiting gate length, from simulations, of about 4 nm. Plasma discharges are used to fabricate hundreds of billions of these nano-size transistors on a silicon wafer. These discharges have evolved from a first generation of “low density” reactors capacitively driven by a single source, to a second generation of “high density” reactors (inductive and electron cyclotron resonance) having two rf power sources, in order to control independently the ion flux and ion bombarding energy to the substrate. A third generation of “moderate density” reactors, driven capacitively by one high and one low frequency rf source, is now widely used. Recently, triple frequency and combined dc/dual frequency discharges have been investigated, to further control processing characteristics, such as ion energy distributions, uniformity, and plasma etch selectivities. There are many interesting physics issues associated with these discharges; an example of electromagnetics effects will be described. Beyond the 4 nm transistor limit lies a decade of further performance improvements for conventional nanoelectronics, and beyond that, a dimly-seen future of spintronics, single-electron transistors, cross-bar latches, and molecular electronics.

Wednesday, June 6, 2007 10:30AM - 12:54PM — Session B1 New Directions in Quantum Control of AMO Systems

10:30AM B1.00001 Developments in the Coherent Control of Collisonal Processes. PAUL BRUWER, University of Toronto — Experimental and theoretical studies of the Coherent Control of unimolecular processes has seen spectacular growth over the last two decades. By contrast, Coherent Control of collisional processes remains a significant challenge. We describe: (1) the entanglement requirement for fixed energy scattering that makes controlled collisional experiments difficult, (2) demonstrate a viable theoretical proposal for control of collision induced ionization, and (3) introduce a time dependent approach that provides a new direction that bypasses entanglement requirements for collisional control. Applications to attosecond scenarios are computationally examined and shown to provide excellent control in the particular cases examined.

1Support from NSERC and PRO is gratefully acknowledged.
In addition as in the other researches on Glauber spin, the spectral response to external field has been investigated. We also have observed the occurrence of SSB as the temperature is changed by illuminating a resonant laser light. Recently we have reported spontaneous symmetry-breaking (SSB) in nonequilibrium atomic system produced by parametrically exciting both in theory and in experiment, experimental studies in non-equilibrium or far-from-equilibrium systems still lack of quantitative investigation and remain as challenging subjects. While critical phenomena in equilibrium systems has been well established this work was supported by NSERC, CFI and ORF, Canada.

Feedback control of open quantum systems is an intriguing new topic for both fundamental and applied research. In this talk I will discuss our group’s ongoing theoretical and experimental work in this area. Our current activity in measurement-feedback control focuses on the development of new methods for quantum precision measurement and sensing. In particular we are trying to understand the utility of feedback control methods in enabling novel quantum metrology protocols, and to elucidate corresponding performance-robustness-complexity tradeoffs. Coherent feedback is an emerging new paradigm for quantum control, in which scattered quantized fields are processed unitarily (without conversion into classical information) and then directed back into the system. We are just beginning a program of research on this topic, aimed at experimental validation of the basic theory.

This work was supported by the NSF and ARO

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KER and angular distributions of H \(^+\) \(n\) having 10\(^{13}\) atoms/cm\(^3\) density of these samples, the lioffe-Regel criterion \(k\ell \sim 0.8\), indicating that localization effects should be evident. Theoretical results on spectral variations of the total scattering

cross section in the strong localization regime are also presented.

\cite{1} Supported by the National Science Foundation

12:18PM B2.00006 Collective self-focusing and atom-optical solitons\(^1\), WILLIAM WILLIAMS, MARK SAFFMAN, University of Wisconsin Madison — We describe collective atom-optical solitons and modulational instability which appear due to mutual self-focusing of light and cold atoms. It is normally impossible to achieve simultaneous focusing since a two-level atom gives self-focusing of light for blue detuning, whereas the dipole potential is attractive for red detuning. Due to saturation effects self-focusing occurs with an attractive dipole potential under conditions of red detuning. We present experimental signatures of this effect observed using cold Cs atoms in a MOT.

\(^1\)This work was supported by the NSF

12:30PM B2.00007 Non-monotonicity in the quantum-classical transition: Chaos induced by quantum effects \(^1\), ARJENDU PATTANAYAK, Carleton College, ARIE KAPULKIN — The transition from classical to quantum behavior for chaotic systems is understood to be accompanied by the suppression of chaotic effects as the relative size of \(\hbar\) is increased. We show evidence to the contrary in the behavior of the quantum trajectory dynamics of a dissipative quantum chaotic system, the double-well Duffing oscillator. The classical limit in the case considered has regular behavior, but as the effective \(\hbar\) is increased we see chaotic behavior. This chaos then disappears deeper into the quantum regime, which means that the quantum-classical transition in this case is non-monotonic in \(\hbar\).

Wednesday, June 6, 2007 10:30AM - 12:54PM —
Session B3 Ultrafast Collision Processes

10:30AM B3.00001 Recollision revisited: How far can we push the classical picture?\(^1\), ANDRÉ STAUDTE, National Research Council of Canada — The double ionization probability of noble gases in strong laser fields at intermediate intensities exceeds the probability that can be expected on grounds of an independent electron picture by several orders of magnitude. Electron-electron correlation is the well-known origin for this dramatic effect. We have revisited this so called nonsequential double ionization in the simplest 2-electron system, the Helium atom, and, using very high resolution coincidence techniques, we observe a surprising structure in the correlated electron momentum distribution. The structure can be interpreted as a signature of the microscopic dynamics in the recollision process, taking the analogy to the classical \((e,2e)\) processes one step further. This interpretation is supported by inspecting the solution of the 2-body 3-dimensional time-dependent Schrödinger equation.

\(^1\)NSERC Centre-of-Excellence for Photonic Innovation, NRC HGF science & technology fund, DFG, BMBF, Alexander-von-Humboldt Foundation.

11:06AM B3.00002 Attosecond control of electron dynamics, MATTHIAS KLING, Max-Planck Institute for Quantum Optics — The availability of laser pulses with a duration down to about a hundred attoseconds opened up the possibility to study the motion of electrons on the timescales where this motion occurs in nature. Control of chemical reactions or photo-biology has been achieved by using laser fields as photonic reagents, which interact with a medium in a manner that is determined by their duration, intensity, frequency, chirp, and polarization. The introduction of phase-stabilized laser pulses now adds new functionality to photonic reagents to control electronic motion. An experiment will be presented on the dissociation of D\(^+\)\(_2\) into D\(^+\) + D by intense few-cycle laser pulses with controlled field evolution, where a pronounced dependence of the direction of the D\(^+\) ejection (and hence of the localization of the electron in the system) on the waveform driving the reaction was observed. Quantum-classical computations reveal that light-field control of molecular electron dynamics is responsible for the observed phenomenon. The possibility to steer electron localization in a molecule and control its dissociation, comprises a completely new way of coherent control that takes place on a sub-femtosecond time scale.

11:42AM B3.00003 Ionization and dissociation of molecular ion beams by intense ultrafast laser pulses\(^1\), ITZIK BEN-ITZHAK, J.R. Macdonald Laboratory, Department of Physics, Kansas State University — Laser-induced dissociation and ionization of a diatomic molecular-ion beam were simultaneously measured using coincidence 3D momentum imaging, with direct separation of the two processes even where the fragment kinetic energy is the same for both processes. We mainly focus on the fundamental H\(^+\)\(_2\) molecule in 7-135 fs laser pulses having 10\(^{13}-10^{15}\) W/cm\(^2\) peak intensity. At high intensities the kinetic energy release (KER) distribution following ionization of H\(^+\)\(_2\) was measured to be broad and structureless. Its centroid shifts toward higher energies as the laser intensity is increased indicating that ionization shifts to smaller internuclear distances. In contrast, a surprising structure is observed near the ionization threshold, which we call above threshold Coulomb explosion (ATCE) \([1]\). The angular distributions of the two H\(^+\)\(_2\) fragments are strongly peaked along the laser polarization, and the angular distribution is described well by \([\cos^4\theta]^{\bar{n}}\), where \(\bar{n}\) is the number of photons predicted by our ATCE model \([1]\). Our data indicates that \(\bar{n}\) varies with the laser wavelength as predicted by the model. The KER and angular distributions of H\(^+\)\(_2\) dissociation change dramatically with decreasing pulse width over the 7-135 fs range in contrast to the reported trend for longer pulses. Others contributing to this work: A.M. Sayler, P.Q. Wang, J. McKenna, B. Gaire, Nora G. Johnson, E. Parke, K.D. Carnes, and B.D. Esry.

Thank are due to Professor Zenghu Chang for providing the intense laser beams and Dr. Charles Fehrenbach for his help with the ion beams.


\(^1\)Supported by the Chemical Sciences, Geosciences, and Biosciences Division, Office of Basic Energy Sciences, Office of Science, U.S. Department of Energy.
12:18PM B3.00004 Laser-induced nonsequential double and multiple ionization of atoms: what can be learned from models \(^1\), WILHELM BECKER, Max-Born-Institut — The significance of a nonsequential channel to double and multiple ionization in some parameter regimes has been long since established. More recently, at least for near-infrared frequencies, consensus has developed that the mechanism is related to recollision of a tunnel-ionized electron with its parent ion. With ab-initio calculations being extremely time consuming, \(S\)-matrix theory allows for comparatively straightforward computation, once the responsible diagrams have been identified.

A crucial element of such a description is the electron-electron interaction that is responsible for the ionization of the second (or more) electron(s) by the first. In this talk, I discuss different choices for this interaction and their consequences for the ion and electron momentum distributions that have been recorded in experiments. I also discuss various methods of how to compute the \(S\)-matrix element, including saddle-point methods that lead to the concept of quantum orbits and a certain limit that is classical but for the initial tunneling of the first electron. If the electron-electron interaction is of contact type, the latter model becomes a statistical model, which only depends on the tunneling rate, the rescattering kinematics, and the volume of phase space for given final momenta. This statistical model can also be applied for an elliptically polarized laser field. For ellipticities exceeding \(\xi \approx 0.3\), interesting effects begin to develop in the momentum distributions.

An additional parameter that reflects the joint action of the electron-electron, electron-ion, and electron-field dynamics, can be introduced by assuming a delay between the time of recollision and the later time when a subset of electrons has thermalized with the returning electron and leaves the immediate vicinity of the ion. The existence of such a delay is supported by classical-trajectory calculations. Comparing model calculations with reality one can infer a value of this delay time. For triple and quadruple ionization of neon, a thermalization time below 500 attoseconds gives good agreement with the existing data. In collaboration with P.B. Corkum, C.F.M. Faria, S.P. Gorelskvi, P.J. Ho, X. Liu, S.V. Popruzhenko, H. Schomerus, and N. Shvetsov-Shilovski.

\(^1\)Supported in part by Deutsche Forschungsgemeinschaft.

Wednesday, June 6, 2007 10:30AM - 12:54PM —
Session B4 Vortices and Solitons in Bose-Einstein Condensates  TELUS Convention Centre Glen 206

10:30AM B4.00001 Exchange of Spin and Orbital Angular Momentum Between an Ultracold Bose Gas and Optical Angular Momentum Beams \(^1\), KEVIN C. WRIGHT, ANDREW B. KOWALIK, University of Rochester, Department of Physics, L. SUZANNE LESLIE, University of Rochester, Institute of Optics, MICHAEL V. PACK, NICHOLAS P. BIGELOW, Rochester, Department of Physics — Atoms and photons possess both spin and orbital angular momentum degrees of freedom, which can be coupled under appropriate experimental conditions. Using Laguerre Gaussian laser beams and cold atoms, we have investigated various aspects of how the spin and orbital angular momentum of the photons couple to either a nondegenerate or degenerate (BEC) Bose gas. In particular, we have focused on exploring the conditions under which it is possible to coherently transfer orbital angular momentum to an ultracold cloud of \(^{87}\)Rb via a two-photon stimulated Raman transition between magnetic sublevels.

10:42AM B4.00002 Persistent flow in a Bose-Einstein condensate \(^1\), PIERRE CLADE, CHANGHYUN RYU, MIKKEL ANDERSEN, VASANT NATARAJAN, ANAND RAMANATHAN, KRISTIAN HELMERSON, WILLIAM PHILLIPS, National Institute of Standards and Technology — We will describe experiments on the study of quantized flow of Bose-condensed atoms in a multiply-connected trap. This torus-shaped trap is formed by the combination of an elliptically shaped, magnetic trap with a blue detuned laser beam in the middle to exclude atoms from the center of the magnetic trap. The rotation was initiated by transferring the orbital angular momentum from Laguerre-Gaussian photons to the atoms. We have observed that the rotational flow of atoms persists for several seconds, even when the condensate fraction is less than 10%. We have also observed flow with high angular momentum and its splitting into singly charged vortices when the trap in no longer multiply-connected.

10:54AM B4.00003 Quantum dynamics of Raman-coupled Bose-Einstein condensates with Laguerre-Gaussian beams \(^1\), RINA KANAMOTO, Department of Physics, The University of Arizona, EWAN WRIGHT, PIERRE MEYSTRE, Department of Physics, College of Optical Sciences, The University of Arizona — We study the quantum dynamics of Bose-Einstein condensates driven by Laguerre-Gaussian light beams. Due to the helical structure of the laser field, the orbital angular momentum of the photon is transferred to the atoms, resulting in a condensate in a coherent superposition of two components with distinct center-of-mass angular momenta. The quantization of the matter-wave field is found to exhibit the collapse and revivals in the resulting interference pattern between two components. The period of the collapse and revivals depends on the U(1) symmetry of the matter wave and is directly observable as the off-axis motion of quantized vortices in the condensate density. We further analyze the steady-state population transfer that can be achieved when applying a time-dependent two-photon detuning.

\(^1\)This work is supported in part by ARO, NASA, ONR, and NSF.

11:06AM B4.00004 Vortex formation by merging multiple trapped Bose-Einstein condensates \(^1\), CHAD WEILER, TYLER NEELLY, DAVID SCHERER, BRIAN ANDERSON, College of Optical Sciences, University of Arizona — We have experimentally studied the merging of three trapped Bose-Einstein condensates. We find that, depending on the rate of merging, the final single BEC may contain a single vortex core (for slow merging rates), or multiple cores (for fast merging rates). Similarly, a triple-well trap may initiate the formation of three isolated BECs, but if the barriers between the wells are weak enough, the condensates merge together during their growth; this process can also lead to the formation of vortices in the final BEC. We interpret both scenarios in terms of interference between the initial uncorrelated condensates with indeterminate relative phases. We will discuss the results and interpretation of this experiment (D.R. Scherer, C.N. Weiler, T.W. Neely, B.P. Anderson, cond-mat/0610187, to be published in Phys. Rev. Lett.).

11:18AM B4.00005 Spontaneous vortex formation during the creation of Bose-Einstein condensates \(^1\), BRIAN ANDERSON, CHAD WEILER, TYLER NEELY, DAVID SCHERER, College of Optical Sciences, University of Arizona — We have experimentally observed spontaneous generation and trapping of quantized vortices in single-component Bose- Einstein condensates. The BECs were created by a standard evaporative cooling procedure in a magnetic trap, without any additional methods of intentionally imparting angular momentum to the trapped atoms. After each BEC was formed, it was expanded such that the presence or absence of a vortex was determined. By observing numerous condensates, the statistical dependence of vortex formation on trapping and cooling parameters was examined. We will discuss our experimental results and our interpretation of the vortex formation mechanism.

11:30AM B4.00006 Collective Excitations of Pinned Vortex Lattice of a Rotating Condensate \(^1\), HAN PU, Rice University, LESLIE BAKSMATY, Georgia Institute of Technology, NICHOLAS BIGELOW, University of Rochester — Using state-of-the-art numerical procedures, we have calculated collective excitation spectrum of the vortex lattice state of a rotating atomic condensate subject to a co-rotating periodic pinning potential. The presence of pinning changes the structure of the excitation spectrum dramatically compared with an unpinned lattice. We have also studied the quantum depletion of the normal modes and its relation to the structure phase transition of the vortex lattice.

\(^1\)supported by National Science Foundation
11:42 AM B4.00007 Signatures of Quantized Vortex States in Rotating Optical Lattices, Brandon Peden, Rajiv Bhat, Meret Krämer, Murray Holland, JILA and Department of Physics, CU Boulder — Recent theoretical studies of ultracold gases in two-dimensional rotating optical lattices have taken advantage of the notion of quantized angular momentum, a quantum number that characterizes the eigenstates of a system with a discrete rotational symmetry. In a gas of strongly interacting bosons, transitions between states of differing quasi-angular momentum have been predicted, implying the entrance of vortices to the lattice. We identify signatures in the linear momentum distribution that distinguish between the different quasi-angular momentum states.

11:54 AM B4.00008 Observation of Phase Defects of a quasi-2D BEC in a Single Dipole Trap, Pierre Claude, Changhyun Ryu, Anand Ramanathan, Kristian Helmerson, William Phillips, National Institute of Standards and Technology — At finite temperature, in a homogeneous two dimensional bosonic gas, long range order is destroyed by thermal fluctuations. For interacting atoms, below a critical temperature, the gas is a superfluid with phase defects consisting of pairs of vortex-antivortex; above this temperature, when the pairs are unbound, the gas enters a normal phase. The nature of the superfluid transition in a non-homogeneous trapped gas has been a topic of some debate. We are studying sodium atoms in a single quasi-2D optical trap. This trap is formed by an elliptical red detuned laser beam and has an aspect ratio of 40. We image the single "pancake" from both sides and observe density fluctuations with time of flight as well as phase fluctuations using Bragg interferometry techniques. Preliminary results provide evidence of the formation of vortex-antivortex pairs in this system.

12:06 PM B4.00009 Use of custom potentials to facilitate access to quantum Hall states in rotating Bose gases, Alexis Morris, David Fedder, University of Calgary — Through the use of exact diagonalization, we have numerically investigated the properties of zero-temperature, harmonically trapped, rotating ultracold Bose gases. For small number of alkali atoms, we consider the case of tight confinement along the axial direction such that the atoms are essentially two-dimensional. As the rotation rate is increased, the interacting Bose gas undergoes a series of transitions from one quantum Hall state to another akin to what is seen in a two-dimensional electron gas subjected to a strong perpendicular magnetic field. Unlike the electronic case, experimental verification of the existence of quantum Hall states in rotating Bose gases has not yet been achieved. To remedy this, we have investigated the possibility of adding custom built potentials to the existing trapping potential such that experimental access to specific quantum Hall states is facilitated. We find that the creation of certain quantum Hall states in rotating Bose gases should be feasible using current experimental capabilities. (Research supported by NSERC, ICORE and CFI)

12:18 PM B4.00010 Quantum phase transitions, symmetry breaking, and the Goldstone mode in metastable Bose-Einstein condensates, Rina Kanamoto, Department of Physics, The University of Arizona, Tucson, AZ, USA, Lincoln Carr, Department of Physics, Colorado School of Mines, Golden, CO, USA, MasaHito Ueda, Department of Physics, Tokyo Institute of Technology, Tokyo, Japan — It is widely believed that the circulation in a repulsive superfluid system is quantized and that there is a discontinuous jump in states between different values of the circulation. We point out that this rule applies only to the ground state, and that continuous transitions between different values of the circulation do occur for metastable states of repulsive Bose-Einstein condensates on a ring. The key to these continuous transitions is the emergence of a dark or grey soliton train that carries a non-integer portion of the circulation. Mean-field theory shows that these continuous changes can be classified as second-order quantum phase transitions between metastable states, where quantized rotation and the soliton state are associated with bifurcations of metastable solutions. We also investigate this problem using quantum field theory, where the broken-symmetry solution and appearance of the Goldstone mode are described by a linear superposition of the quasigenerate eigenstates of the many-body Hamiltonian.

12:30 PM B4.00011 ABSTRACT WITHDRAWN

12:42 PM B4.00012 Nonlocal stabilization of nonlinear beams in a self-focusing atomic vapor, Mark Saffman, University of Wisconsin Madison, Stefan Skupin1, Wieslaw Krolikowski, Research School of Physical Sciences and Engineering, Australian National University, Canberra, ACT 0200, Australia — We show that ballistic transport of optically excited atoms in a hot atomic vapor provides a nonlocal nonlinearity which stabilizes the propagation of vortex beams and higher order modes in the presence of a self-focusing nonlinearity. Numerical experiments demonstrate stable propagation of lowest and higher order vortices over a hundred diffraction lengths, before dissipation leads to decay of these structures.

1Present address Département de Physique Théorique et Appliquée, CEA/DIF, B.P. 12, 91680 Bruyères-le-Châtel, France

Wednesday, June 6, 2007 10:30 AM - 12:42 PM
Session B5 Metrology & Electric Dipole Moments
TELUS Convention Centre Glen 205

10:30 AM B5.00001 Slow-Atom Electron EDM Experiment with Electric Field Quantization, Harvey Gould, Jason Amini2, LBNL, Charles Munger Jr., SLAC — Improving the electron electric dipole moment (e-EDM) upper limit has been a 40-year battle against systematic effects. Two new weapons in this battle are slow atoms and ground-state electric field quantization, both of which suppress motional magnetic field effects. They have been used effectively in a recently completed e-EDM experiment that is a prototype for a high-sensitivity Cs fountain e-EDM experiment. Electric field quantization of Cs atoms requires nulling residual magnetic fields to < 300 pT, transport of polarized atoms through field-free (nulled) regions, and inducing transitions between closely spaced |mF| levels using separated short pulses in place of oscillatory fields. The possibility of improving the e-EDM limit with a Cs fountain experiment will be discussed.

1Supported by NASA and by a NIST Precision Measurements Grant

2Present affiliation, NIST, Boulder CO

10:42 AM B5.00002 An Electron EDM Search Using Trapped Molecular Ions, Laura Sinclair, John Bohn, Aaron Leanhardt, Edmund Meyer, Russell Stutz, Eric Cornell, JILA, NIST, and the Department of Physics, University of Colorado, Boulder, CO 80309 USA — A sample of trapped molecular ions offers unique possibilities to search for a permanent electron electric dipole moment (EDM). Specifically, we plan to perform this search using the unpaired electron spins in the +1 state of trapped HfF+ molecular ions. Ions are easy to trap which will provide the long coherence times necessary to measure the small energy differences associated with an electron EDM. Additionally, the internal electric fields in polarized diatomic molecules can exceed 1010 V/cm, which will amplify any EDM induced energy splittings. We have created HfF+ ions in a supersonic expansion jet by ablating a Hf target with a pulsed Nd:YAG laser in a He + 1%SF6 environment. The chemical reaction HfF+ + SF6 → HfF+ + SF5 is exothermic and proceeds rapidly. The He buffer gas in the expansion cools the molecular translational, vibrational, and rotational degrees of freedom to ~ 10 K. We have measured these temperatures via laser induced fluorescence spectroscopy on known neutral Hf atomic lines and newly identified neutral HfF molecular lines, and are currently searching for the unknown HfF+ electronic transitions.
10:54AM B5.00003 Progress Towards a New Measurement of the Electric Dipole Moment of $^{199}\text{Hg}$

M.D. SWALLOWS, W.C. GRIFFITH, B.R. HECKEL, E.N. FORTSON, University of Washington, M.V. ROMALIS, Princeton University — We are currently undertaking a four vapor cell search for the permanent electric dipole moment (EDM) of $^{199}\text{Hg}$. The existence of a nonzero EDM would imply a source of CP violation beyond the standard model. The present limit on the EDM of $^{199}\text{Hg}$ is $|\delta q_{199}| < 2.1 \times 10^{-28} \text{ e cm}$, which was established several years ago by our group at the University of Washington. In that experiment, two quartz vapor cells containing polarized Hg vapor were placed in parallel magnetic and anti-parallel electric fields (the use of two cells permitted the removal of common-mode effects), and the spin precession frequency was measured using an optical technique. In our current experiment, two additional cells at zero electric field serve to cancel magnetic gradient noise and to improve limits on systematic effects due to charging and leakage currents. We have recently overcome several systematic issues and begun acquiring data with our upgraded apparatus. To prevent experimenter bias from influencing the data, we have also instituted a blind analysis protocol. The statistical error of the data at the time of this writing was $\pm0.15 \times 10^{-28} \text{ e cm}$, and we hope to improve the sensitivity by a further factor of two. We will discuss recent progress and our plans to place improved limits on systematic effects.

11:06AM B5.00004 Toward Searches for Electric Dipole Moments of Radium

SUBHADEEP DE, UMAKANTH DAMMALAPATI, KLAUS JUNGMANN, ARAN MOL, LORENZ WILLMANN, KVI, Rijksuniversiteit Groningen — Within the TRIP (Trapped Radioactive isotopes micro - laboratories for fundamental Physics) programme we are performing experiments searching for violation of discrete symmetries (Parity (P), Time reversal (T) and Charge conjugation (C)) in fundamental interactions. This allows to test various possible extensions to the standard model of the electro-weak interactions. In particular we are searching permanent electric dipole moment (edm) which violates both P and T. The radium (Ra) isotope $^{210}\text{Ra}$ offers several orders of magnitude ($\geq 10^5$) enhancement of an edm signal compare to any other system due to their atomic structure [1]. Laser cooling and trapping is an essential tool to increase sensitivity of such an experiment. Possible laser cooling schemes for radium involve leaky cooling transitions. Magneto optical trapping of atoms with a leaky transition requires improvement of the known cooling techniques. As an example we demonstrate laser cooling of barium. We successfully slowed barium atoms from a thermal atomic beam.


11:18AM B5.00005 Accurate determination of the electric-dipole matrix elements in K and Rb from the Stark shift measurements

MARIANNA SAFRONOVA, BINDIYA ARORA, University of Delaware, CHARLES W. CLARK, National Institute of Standards and Technology, Gaithersburg — Stark shifts of the rubidium and potassium D1 lines have been measured with high precision by Miller et al [1]. In this work, we combine these measurements with our all-order calculations to determine the values of the electric-dipole matrix elements for the $4p_j - 3d\ell_j$ transitions in K and for the $5p_j - 4d\ell_j$ transitions in Rb to high precision. These transitions contribute on the order of 90% to the respective polarizabilities of the $np_{1/2}$ states in K and Rb, and the remaining 10% can be accurately calculated using the relativistic all-order method. Therefore, the combination of the experimental data and theoretical calculations allows to determine the $n\ell - (n-1)d$ matrix elements and their uncertainties. We also compare these values with our all-order calculations for a benchmark test of the accuracy of the all-order method for transitions involving nd states. Such matrix elements are of special interest for many applications, such as determination of the “magic” wavelengths in alkali-metal atoms for state-insensitive cooling and trapping and determination of blackbody shifts in optical frequency standards with ions.


11:30AM B5.00006 State-selective ionization of lead monofluoride

C.P. MCRAVEN, P. SIVAKUMAR, N.E. SHAFER-RAY, University of Oklahoma — Lead monofluoride is an important molecule in the search for the electron electric dipole moment. We have developed a doubly resonant photoionization scheme for complete rotational state sensitivity of the ground state. Experimental details and spectroscopic constants are presented.

11:42AM B5.00007 Precision Mass Spectrometry and Polarizability Shifts with Two Ions in a Penning Trap

MATTHEW REDSHAW, JOSEPH MCDANIEL, ELIZABETH WINGFIELD, BRIANNA MOUNT, EDMUND MYERS, Florida State University — We have implemented a technique for precise mass spectrometry with two ions simultaneously confined in a Penning trap in which each ion is alternately positioned at the center of the trap - where the cyclotron frequency is measured - or else parked in a large cyclotron orbit [1]. We have resolved previous systematic errors and have been able to exploit the improved statistical precision available with this technique. We have now used this technique to measure the mass ratios $^{31+}/^{28}\text{Si}^{1+}$, $^{25}\text{Si}^{1+}/^{13}\text{C}^{2+}$, and $^{28}\text{Si}^{1+}/^{12}\text{C}^{3+}$ to obtain new values for the atomic mass of $^{28}\text{Si}$ and $^{31}\text{P}$. In addition we have studied the ratio $^{31}\text{PH}^{1+}/^{32}\text{O}^{2+}$ to measure shifts in the cyclotron frequency of $^{31}\text{PH}^{+}$ due to the interaction between the ion’s polarizability and the motional electric field. This has led to a measurement of the polarizability and dipole moment of $^{31}\text{PH}^{+}$. [1] M. Redshaw, J. McDaniel, W. Shi and E. G. Myers, Int. J. Mass Spec. 251, 125 (2006).

1 Supported by part by NSF PHY-0354741 and NIST

11:54AM B5.00008 Blackbody radiation shift in optical frequency standard with $^{48}\text{Ca}^{+}$ ion

BINDIYA ARORA, M.S. SAFRONOVA, University of Delaware, CHARLES W. CLARK, National Institute of Standards and Technology, Gaithersburg — The static polarizabilities of $\text{Ca}^{+}$ ion in the $4s_{1/2}$ ground and $3d_{5/2}$ excited states are calculated to high precision. The calculations are based on the relativistic all-order single-double method where all single and double excitations of the Dirac-Hartree-Fock wave function are included to all orders of perturbation theory. The accuracy of the all-order electric-dipole matrix elements for the $4s - np_{1/2}$, $4s - np_{3/2}$, $4d_{5/2} - np_{1/2}$, $4d_{3/2} - np_{3/2}$, $3d_{5/2} - nf_{1/2}$, and $3d_{5/2} - nf_{3/2}$ transitions needed for the polarizability calculations is investigated. Additional calculations are conducted for the dominant contributions in order to evaluate some omitted high-order corrections and evaluate the resulting uncertainties in the polarizability values. We use the the polarizability values to calculate the black body radiation shift in $4s_{1/2} - 3d_{5/2}$ transition of $\text{Ca}^{+}$ ion at room temperature ($T=300 \text{ K}$) and its uncertainty. The tensor polarizability of the $3d_{5/2}$ level is also calculated and its uncertainty is evaluated as well. Our results are compared with other calculations. This work is motivated by a prospect of optical frequency standard based on a $^{48}\text{Ca}^{+}$ ion.

12:06PM B5.00009 A Thermal-beam Calcium Interferometer

CHRISTOPHER ERICKSON, MARSHALL VAN ZILL, MATTHEW WASHBURN, JAMES ARCHIBALD, DAN CHRISTENSEN, JEREMIAH BIRRELL, ADAM BURDATT, DALLIN DURFEE, Brigham Young University — We report on the construction of a next-generation atom interferometer. Our research includes developing passive stabilization techniques, low-noise laser current drivers, high-speed scan-balancing lock circuits, and high-speed low-noise photo-detecting units. Our efforts have lead to developing an extremely stable laser locked to an ultra-high finesse optical cavity for use in a Ramsey-Bordé interferometer scheme. The interferometer itself is based on a thermal calcium beam and will be upgraded in the future to a dual species Ca/Sr interferometer sensitive enough to improve measurements of possible time variance of the fine structure constant.
12:18PM B5.00010 New search for a spin-gravity interaction. DEREK KIMBALL, California State University - East Bay — We are beginning an experiment to search for a new long-range coupling between nuclear spins and the mass of the Earth. If interpreted as a limit on a spin-gravity interaction of the form $S \cdot g$ between nuclear spins $S$ and the gravitational field of the Earth $g$, the experiment would improve present experimental limits by over two orders of magnitude. The presence of such an interaction would be evidence that gravity violated parity and time-reversal symmetries to a small degree, as well as being a breakdown of the equivalence principle which underlies the theory of general relativity. The experiment would set new experimental limits on hypothetical scalar and vector components of gravitational fields. This new experimental search is motivated by recently developed techniques in the field of atomic magnetometry enabling significant improvement in sensitivity to atomic spin precession. The experiment will use nonlinear optical rotation of near-resonant laser light to measure the spin-precession frequency of alkali atoms in the presence of a magnetic field $B$. The difference between the precession frequencies for the two different ground state hyperfine levels yields a signal proportional only to anomalous interactions that do not scale with the magnetic moments of the atoms. The sum of the precession frequencies enables ultra-precise determination of $B$ to correct for associated systematic errors.

Wednesday, June 6, 2007 10:30AM - 12:54PM –
Session B6 Rydberg Atoms and Molecules
TELUS Convention Centre Olde Scotch Room

10:30AM B6.00001 Rydberg Multipole Transitions in Time-Dependent Ponderomotive Potentials$^{1}$, B. KNUFFMAN, G. RAITHEL, University of Michigan — We consider multipole transitions in Rydberg atoms driven by amplitude modulation of an applied standing-wave ponderomotive potential. Using experimentally realizable parameters, we calculate Rabi frequencies of tens of kHz. Dipole selection rules are not applicable to these transitions, which can occur between states whose angular momentum quantum numbers can differ up to about five. Experimental schemes to measure the quantum defects of high angular momentum states using this technique are discussed.

$^{1}$FOCUS Center & Michigan Center for Theoretical Physics

10:42AM B6.00002 Enhancement of Rydberg atom interactions using ac Stark shifts$^{1}$, JOSEPH PETRUS, PARISA BOHLOLUI-ZANJANI, JAMES MARTIN, Department of Physics and Astronomy and Institute for Quantum Computing, University of Waterloo, Waterloo, ON, N2L 3G1, Canada — A microwave dressing field was used to induce resonant energy transfer in translationally cold Rydberg atoms. The $^{85}$Rb Rydberg atoms were obtained by laser excitation of cold atoms in a magneto-optical trap. When the amplitude of a $1.356$ GHz dressing field was scanned, the two-atom dipole-dipole process $43d_{5/2} + 45d_{5/2} \rightarrow 45p_{3/2} + 41f_{5/2}$ was enhanced due to the induced degeneracy of the initial and final states. The resulting spectrum had a series of resonant field amplitudes corresponding to different magnetic sublevels possible for the states involved. The scanned field amplitude was calibrated using microwave spectroscopy of the $43d_{5/2} \rightarrow 41f$ transition under the influence of non-resonant dressing fields. The calibrated resonant field amplitudes agree well with ac Stark shift calculations performed using the Floquet approach. This method for enhancing interactions is complementary to dc electric field induced resonant energy transfer, but benefits from the ability to shift energy levels in either direction by choice of frequency.

$^{1}$Work supported by NSERC, CFI and OTT.

10:54AM B6.00003 Resonant enhancement of state-mixing and ionizing collisions in Rb Rydberg states$^{1}$, AARON REINHARD, TARA CUBEL LIEBISCH, PAUL BERMAN, GEORG RAITHEL, The University of Michigan — In rubidium Rydberg states, the binary collision $2 \times nD_{3/2} \rightarrow (n-2)F_{7/2} + (n+2)P_{3/2}$ is nearly resonant in the vicinity of $n = 43$. As a result, over a short range of $n$ centered around $n \approx 43$ the two-particle interaction potential is quite large and turns from repulsive to attractive. This behavior has interesting consequences for the rates of Penning-ionizing and state-changing collisions in Rydberg-atom gases and for Rydberg-excitation blockades. In this talk, we report the use of state-selective field ionization to investigate the effect of this resonance on coherent excitation of mixed two-particle states, state-mixing collisions, and Penning-ionization. In particular, we excite superpositions of the two-particle states $2 \times nD_{3/2}$ and $(n-2)F_{7/2} + (n+2)P_{3/2}$ and show that the cross section for subsequent state-changing collisions is a strong function of $n$ near $n = 43$. We find that the dynamics of state-mixing collisions and the evolution of the Rydberg gas to a cold plasma depend sensitively on the sign of the interaction potential, and thus on $n$ near the resonance. We compare these results with cases where the atoms are initially excited into states of different $f$ and $j$.

$^{1}$FOCUS Center and Michigan Center for Theoretical Physics

11:06AM B6.00004 Spatially resolved observation of dipole-dipole interaction between Rydberg atoms, CAROLIJN VAN DITZHUIZEN, Van der Waals-Zeeman Instituut, University of Amsterdam, FEMIUS KOENDERINK, FOM-Institute for atomic and molecular physics, Amsterdam, ATREJU TAUSCHINSKY, BART NOORDAM, BEN VAN LINDEN VAN DEN HEUVELL, Van der Waals-Zeeman Instituut, University of Amsterdam — We have observed resonant energy transfer between cold Rydberg atoms in separate volumes. Two pulsed laser beams are focused in a $^{87}$Rb MOT, with waist sizes of $\sim 10 \mu m$. In one laser focus $\sim 10$ atoms are excited to the $49s$ state and in the other $\sim 60$ atoms are excited to the $41d$ state. At a field of $0.4 V/cm$ a resonant dipole-dipole coupling occurs with a wavelength of $1 cm$: $41d + 49s \rightarrow 42p + 49p$. We have measured the production of the $49p$ state as a function of laser focus separation ($0 - 80 \mu m$) and interaction time ($0 - 50 \mu s$). The procedure can be understood as writing a 0 bit ($49p$) in volume $A$ and a 1 bit ($41d$) in volume $B$. The bit in $A$ goes from 0 to 1 ($49p$) and the bit in $B$ from 1 to 0 ($42p$), due to the dipole-energy transfer from $B$ to $A$.
11:18AM B6.00005 Investigation into the Dipole-Dipole Interaction between Two Localized Groups of Rydberg Atoms. PETER D. MAENNER, Bryn Mawr College, THOMAS J. CARROLL, Swarthmore College, MICHAEL W. NOEL, Bryn Mawr College — Atoms in a highly excited, ultracold sample are coupled through the dipole-dipole interaction. The interactions resulting from a sample are complicated, and an effort has been made to understand and control them. In our experiment, we have investigated how the spatial arrangement of highly excited atoms affects the dipole-dipole interaction strength. Two tunable dye lasers were focused into a magneto-optical trap, producing a sample consisting of two localized groups of Rydberg atoms. Each group was excited to a different state, such that only interactions possible were between the different groups of atoms. The dipole-dipole interaction was tuned into resonance with a static electric field. Varying the beam separation, we measured the number of interacting atoms and width of the field tuned resonance peak.

11:30AM B6.00006 Coherent many-body dynamics in cold Rydberg gases. THOMAS POHL, ITAMP, Harvard-Smithsonian Center for Astrophysics, Cambridge, MA, MIKHAIL D. LUKIN, Physics Department, Harvard University, Cambridge, MA — Recent realizations of ultra-cold ensembles of Rydberg atoms opens up unique possibilities for exploring non-equilibrium quantum dynamics of many-body systems with strong, long-range interactions. Here we will report on theoretical progress in describing the evolution of Rydberg populations in cold gases for various types of interactions. Special emphasis will be placed on excitation schemes that provide a more intuitive understanding of the gas evolution and reveal effects of atomic disorder and quantum correlations on the collective excitation dynamics.

11:42AM B6.00007 Radiative lifetime measurements of high-\(n\) Rb Rydberg states. DUNCAN TATE, MAO ZHENG, DREW BRANDEN, TAMAS JUHASZ, Colby College, ANDREW KORTYNA, Lafayette College — We have measured the radiative lifetimes of \(S\), \(P\), and \(D\) states of rubidium in the range \(30 \leq n < 50\) using cold atoms in a MOT. Two experimental techniques have been adopted to reduce random and systematic errors. First, a frequency doubled, pulse amplified diode laser is used to excite the target \(n\)\(^P\) Rydberg state. The output from this laser has a Fourier-transform linewidth of \(\approx 100\) MHz at 480 nm, and results in minimal shot-to-shot variation in the Rydberg state population. When it is used to drive the \(5\Pi_{1/2} \rightarrow n\)\(^P\) transition. Second, we monitor the state population as a function of time delay from the 480 nm laser pulse using a short mm-wave pulse that is resonant with the two-photon transition \(n\)\(^P\) \(\rightarrow (n+1)\). We then selectively field ionize the \((n+1)\) state, and detect the resulting electrons with a microchannel plate (MCP). We step the time delay between the laser pulse and the mm-wave pulse and acquire the MCP signal as a function of the delay. This signal is an accurate mirror of the \(n\) population, which we fit to an exponential decay to recover the \(n\) state lifetime.

11:54AM B6.00008 Resonant collision processes in a Cs Rydberg gas. DUNCAN TATE, MOHAMMED ELHAYAAN, ARNE SCHWETTMANN, JONATHAN TALLANT, JAMES P. SHAFFER, The University of Oklahoma — We have calculated high-lying cold long-range Cs Rydberg molecules. We show bound molecular states at large interatomic distances of \(\approx 5\) microns, entirely due to avoided crossings of the Van der Waals pair-interaction potentials. These wells were found in the full set of long-range multipole Rydberg-Rydberg interaction potential curves calculated by our group via matrix diagonalization. The well-depths are enhanced by the application of a small (mV) background electric field. Corresponding bound state wavefunctions are analyzed. Methods to excite and observe these long-lived \((\tau > \mu s)\) molecular states will be discussed. Experimental progress toward observing these novel molecular states will also be presented.

We acknowledge funding from the Research Corporation, the OSRHE and the Air Force Office of Scientific Research (FA9550-05-0328).

12:06PM B6.00009 Long-range Cs Rydberg molecules. ARNE SCHWETTMANN, JONATHAN TALLANT, JAMES P. SHAFFER, The University of Oklahoma — We have calculated high-lying cold long-range Cs Rydberg molecules. We show bound molecular states at large interatomic distances of \(\approx 5\) microns, entirely due to avoided crossings of the Van der Waals pair-interaction potentials. These wells were found in the full set of long-range multipole Rydberg-Rydberg interaction potential curves calculated by our group via matrix diagonalization. The well-depths are enhanced by the application of a small (mV) background electric field. Corresponding bound state wavefunctions are analyzed. Methods to excite and observe these long-lived \((\tau > \mu s)\) molecular states will be discussed. Experimental progress toward observing these novel molecular states will also be presented.

We acknowledge funding from the Research Corporation, the OSRHE and the Air Force Office of Scientific Research (FA9550-05-0328).

12:18PM B6.00010 Measurements in high-L, \(n=17\) and 20 Rydberg states of barium: An investigation of ion core properties of Ba\(^{+1}\). ERICA L. SNOW, SUNY Fredonia, STEPHEN R. LUNDEEN, Colorado State University — Microwave spectroscopy studies with selective laser excitation for detection of Rydberg levels by Stark ionization have been used to measure the fine structure intervals of \(n=17\) and 20 for a range of angular momentum states, \(7 \geq L \geq 11\). Measurement of the energy splittings in the fine structure levels, due largely to interactions of the Rydberg electron’s angular momentum with the ion core spin, are also reported. The implications of these measurements on the determination of the ion core properties, such as the polarizability and lifetimes, and associated matrix elements is investigated.

Supported by U.S. Department of Energy

12:30PM B6.00011 Higher-order contributions to fine structure in high-L Rydberg states of Si\(^{2+}\). ERICA L. SNOW, SUNY Fredonia, STEPHEN R. LUNDEEN, Colorado State University — Measured fine structure patterns of high-L Rydberg states of Si\(^{2+}\) have often been used to extract measurements of both dipole and quadrupole polarizabilities of their positive ion cores. Dipole polarizabilities deduced in this way are apparently quite accurate, judging by comparison with calculated values, but the accuracy of quadrupole polarizabilities is questionable. The polarizabilities of Na-like silicon are a good example. Recent fine structure measurements seem to imply a quadrupole polarizability in clear disagreement with calculations. This apparent discrepancy is due to misinterpretation of the experimental data, neglecting the effects of higher-order terms in the polarization potential that can significantly alter the slope of the traditional polarization plots. When these terms are calculated, and their magnitude estimated, the discrepancy is eliminated. The implications of the higher order terms for analysis of high-L fine structure patterns are discussed.

Supported by U.S. Department of Energy

\(^1\)This work is supported by NSF grant #0134676.

\(^3\)This work is supported by NSF grant #0134676.
12:42PM B6.00012 Polarizability of Kr$^{6+}$ from High-L Kr$^{5+}$ Fine Structure Measurements1. S.R. LUNDEEN, Colorado State University, C.W. FEHRNBACK, Kansas State University — The transition between n=55 and n=109 Rydberg levels of Kr$^{5+}$ has been studied at high resolution using the RESIS method. Resolved excitation of L = 6, 7, 8, and 9 levels in n=55 lead to a determination of the fine structure energies of these levels. Interpreted with the long-range polarization model, this leads to a measurement of the dipole polarizability of Zn-like Kr$^{6+}$, α_d = 2.53(2) a_0^3. Considerations involved in deducing a value of the quadrupole polarizability from the data and factors contributing to the signal and noise levels in measurements of this type will be discussed.

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

Wednesday, June 6, 2007 1:30PM - 3:54PM –
Session C1 DAMOP TGPMFC: Cold Molecules TELUS Convention Centre Macleod BC

1:30PM C1.00001 Molecular collision studies with Stark-decelerated beams, GERARD MEIJER, Fritz Haber Institute of the Max Planck Society — Molecular scattering behavior has generally proven difficult to study at low collision energies. We formed a molecular beam of OH radicals with a narrow velocity distribution and a tunable absolute velocity by passing the beam through a Stark decelerator. The transition probability for inelastic scattering of the OH radicals with Xe atoms were measured as a function of the collision energy in the range of 50 to 400 wavenumbers, with a high intrinsic energy resolution. The behavior of the cross-sections for inelastic scattering near the energetic thresholds was accurately measured; and excellent agreement was obtained with cross-sections derived from coupled-channels calculations on ab initio computed potential energy surfaces [Science 313 (2006) 1617-1620]. The possibilities to perform collision studies using either two Stark-decelerated beams in a crossed beam configuration or counter-propagating packets of molecules in a molecular synchrotron [Nature Physics, published online January 21, 2007; doi:10.1038/nphys131] will be discussed.

Our experimental approach to the sympathetic cooling of polar molecules with ultra-cold Rb atoms will be presented as well. Time-permitting, measurements on the optical pumping of trapped polar molecules by black-body radiation [arXiv:physics/061221v] as well as our latest results on the electrodynamic (AC) trapping of, both, ground-state atoms and molecules [PRA 74 (2006) 06403] will be shown.

2:06PM C1.00002 Experiments with Ultracold KRb and Rb$_2$ Molecules1. PHILLIP GOULD, University of Connecticut — Ultracold molecules are of interest for a number of applications including ultracold chemistry, novel quantum degenerate systems, precision spectroscopy, and quantum computation. Photoassociation (PA) of ultracold atoms is a useful means of producing various diatomic molecular species at sub-mK temperatures. Heteronuclear systems have garnered particular attention because of their permanent electric dipole moments. We use PA to form both KRb and Rb$_2$, typically in high vibrational levels of either the singlet ground state (X\(^1\Sigma^+\)) or lowest-lying triplet state (\(\alpha\ ^3\Sigma^-\)). In KRb, a novel depletion spectroscopy is used to detect the molecules with both vibrational (\(\nu\)) and rotational (\(J\)) resolution. Monitoring the population of a specific X-state vibrational level \(v''\) with pulsed two-photon ionization, we observe depletion when a cw laser drives a bound-bound transition from \(v''\) to \(J''\) to an excited rovibrational level. This high-resolution spectroscopy is helping to guide Raman schemes to transfer ultracold molecules from high-\(v''\) levels, produced by PA, to the absolute ground state, which is stable against inelastic collisions. We also use this depletion spectroscopy to precisely measure the ground-state dissociation energy of KRb. In Rb$_2$, we observe the effects of resonant coupling between excited 0\(^1\nu\) states on ground-state molecule formation. We photoassociate to 0\(^1\nu\) levels below the 5S + 5F\(_{1/2}\) limit and state-selectively detect the resulting ground-state molecules by two-photon ionization. In the absence of resonant coupling between the two 0\(^1\nu\) potentials (converging to the 5S + 5P\(_{1/2}\) and 5S + 5P\(_{3/2}\) limits), the excited molecules would spontaneously decay overwhelmingly to the highest \(v''\) levels, bound by \(< 1\) cm$^{-1}$. The effect of resonant coupling is to provide selected 0\(^1\nu\) wavefunctions with increased short-range amplitude, which enhances their decay to more deeply bound levels. Progress towards optical trapping and collisional studies of Rb$_2$ will also be reported.

1This work was done in collaboration with D. Wang, J.T. Kim, H.K. Pechkis, Y. Huang, C.P. Koch, E.E. Eyler, and W.C. Stwalley, and supported by the NSF.

2:42PM C1.00003 New theoretical findings on cold molecules in optical lattices, SVETLANA KOTCHIGOVA, Temple University — There are great expectations for the application of ultra-cold molecules in simulating many-body states and performing high-precision measurements. All these applications are based on optical lattices to hold molecules in fixed spatial locations. Optical lattices are constructed from the interference patterns of counter-propagating laser beams. They provide a periodic potential for ultracold particles. The parameters of the lattice can be externally controlled by tuning the frequency and intensity of the lasers. In addition, the interaction strength between polar molecules can be tuned by external DC electric or magnetic fields. There are many things that have to be found about polar molecules in optical lattices before these goals are reached. In particular, I have focused on determining the most efficient ways to produce molecules from ultra-cold atoms in optical lattices. I will discuss conditions for strong confinement of molecules in a lattice, suppression of undesired perturbations that cause loss of atoms and molecules from the lattice, and control interactions between neighboring molecules. In addition, I will show our results on the differential AC Stark shift of various ro-vibrational levels of the ground-state molecules caused by the optical lattice. The analysis of Stark shifts are essential for selection of vibrational levels with matched polarizabilities as necessary for high-precision frequency measurements. I acknowledge support of this work from a grant of the Army Research Office.

3:18PM C1.00004 Creating and confining ultracold polar molecules1. NICHOLAS BIGELOW, University of Rochester — We describe our work on the creation of ultracold (T\(< 200\ \mu\)K) NaCs molecules. Our experiments start with electronic ground-state NaCs molecules created by photoassociation of laser cooled and trapped Na and Cs atomic vapors held in a two-species magneto-optical trap. Using state-resolved photoassociation followed by resonantly enhanced multi-photon ionization we have carried out a detailed spectroscopic study of this system and show that a significant number of deeply bound singlet-state molecules can be created. We then describe our recent success in trapping the singlet molecules. Finally, we discuss approaches to manipulate the state of these molecules using a laser-controlled state transfer scheme.

1This work is supported by the National Science Foundation and the Army Research Office.
Furthermore the RF coupling allows many different potential shapes to be realized, including a 2d cylinder shaped trap. The later allows to create a 2d condensate with periodic boundary conditions which exhibits peculiar interference. In addition combining the AtomChip with a 1d optical lattice of 2d planes we observe coherent Bloch oscillations close to the AtomChip surface [5], which gives us a new tool for coherent manipulation of 2d mesoscopic quantum gases. 

2:06PM C2.00002 On-chip Bose-Einstein condensate interferometer with 0.5 mm arm length

We demonstrate a chip-based Michelson interferometer for Bose-Einstein condensates in which a harmonic trap reflects the atoms. The condensate is split by diffraction from momentary exposure to an off-resonant standing light field. The two clouds propagate in opposite directions along a waveguide having a weak (6 Hz) harmonic axial confinement. The condensates reflect from the axial potential at classical turning points separated by about 0.5 mm. Upon returning to the trap center, the two clouds are recombined by a second exposure to the standing light field. The resulting three clouds are allowed to remain in the guide for a brief time. The atoms are then released from the guide and imaged after 15 ms of ballistic expansion. The total propagation time can be set to 80 or 160 ms. We use principal component analysis of a set of many images to study the coherence of the recombined atoms.

3:00PM C2.00004 Matter wave interferometry with phase fluctuating condensates

Since quasi-1D condensates created on atom chips are typically in the phase fluctuating regime with a phase coherence length shorter than the spatial extent of the cloud, the presence of the fluctuation may degrade interference fringes and, consequently, erase the relative phase information in the fringes. In the experiment, we produce a double-well potential in the plane parallel to the inter-condensate separation by deforming a single well using adiabatic rf-induced splitting. We observe a decrease in the fringe contrast as the temperature increases, indicating that fringes become wavier at higher temperature. We also discuss the effect of fluctuations on the phase coherence of the split condensates.

4:00PM C2.00006 An experiment to measure the electric polarizability of $^{87}$Rb using a condensate interferometer

We have demonstrated a condensate interferometer with coherence time over 70 ms and arm separations over 200μm, which allows each packet to be individually accessible. We plan to use this device to measure the electric polarizability of $^{87}$Rb by applying a precise electric field to one packet and not the other. By observing the resulting phase shift, we expect to be able to extract the polarizability with a relative accuracy better than $10^{-3}$. We will report on the experimental developments.

2:18PM C2.00003 Phase Sensitive Recombination of two Bose-Einstein Condensates on an Atom Chip

The recent realization of a single weak link for an atomic Bose-Einstein condensate in an optical double-well potential allows for the first time observation of coherent Josephson oscillations directly on the level of populations on either side of the junction. Furthermore it opens up the way to fully characterize the tunneling dynamics since not only the dynamics of the population difference can be measured but even the time evolution of the relative phase is detectable. How the residual interaction of the atoms can lead to a new dynamical regime, which is characterized by an inhibition of tunneling, will be discussed in detail. The well controlled experimental setup of the atom system allows for a quantitative study of thermally induced fluctuations of the relative phase between the weakly linked condensates. The experimentally observed fluctuations are in quantitative agreement with the theoretical predictions and give insight into the coherence of two weakly coupled condensates. Since the thermal fluctuations exist for any non-zero temperature their measurement can be employed as a new type of primary thermometer for atomic Bose-Einstein condensates working in a regime were standard methods such as time of flight fail. Our recent results on the heat capacity of a quantum gas at ultra low temperatures using this new noise-thermometer will be presented.
3:30PM C2.00007 Obtaining a high-visibility Bose-Einstein condensate interferometer

K. JERAMY HUGHES, BENJAMIN DEISSLER, JOHN H.T. BÜRKE, CASS SACKETT, University of Virginia — We have previously reported on an atom interferometer based on Bose-Einstein condensates of $^{87}$Rb in a weakly confining magnetic trap [1]. Previous results were limited to interference visibilities of about 1/2 and coherence times of about 45ms. We have identified several effects that limited these figures, including motional excitation of the condensate, spatial noise in the coupling laser beams, and noise in the magnetic trap currents. Resulting improvements to the apparatus have increased the interferometer visibility to near unity for short times, and have permitted operation at times over 70ms. We will report on our current performance.


3:42PM C2.00008 Theoretical analysis of cold atom interferometers with optical control of dynamics

JAMES STICKNEY, WPI, DANA Z. ANDERSON, University of Colorado and National Institute of Standards and Technology, ALEX ZOZULYA, WPI — Atom interferometers using Bose-Einstein condensate that is confined in a waveguide and manipulated by optical pulses have been limited by their short coherence times. We present a theoretical model that offers a physically simple explanation for the loss of contrast for both a single-pass and double-pass interferometers. For the case of a single-pass device, we propose the method for increasing the fringe contrast by recombining the atoms at a different time. A simple, quantitatively accurate, analytical expression for the optimized recombination time is presented and used to place limits on the physical parameters for which the contrast may be recovered. For the case of a double-pass interferometer, we place an upper limit on the device’s coherence time.

3:54PM C2.00009 Gold coated nano gratings for atom optics

VINCENT LONIJ, JOHN PERREAULT, University of Arizona, Tucson, OLEG KORNILOV, Max Planck Institute, Goettingen, ALEX CRONIN, University of Arizona, Tucson — The Van der Waals (VdW) interaction between neutral atoms is important to the dynamics of mechanical systems on nanometer scales. We used diffraction of sodium atoms from nano gratings to measure the Van der Waals potentials for atoms and different surfaces with improved precision. Atoms passing through the grating acquire an additional phase shift due to the attractive potential between the atoms and the grating bars, causing the diffraction pattern to be modified [1]. Previous measurements reported the VdW coefficient for sodium atoms and a silicon-nitride(SiNx) surface [2]. In our experiment we used a SiNx grating coated with a 2 nm layer of gold and we were able to measure a 40% increase in the VdW coefficient due to the gold. We also improved precision by combing results from the sodium diffraction experiment with results from a diffraction experiment with helium atoms on the same gratings.


4:06PM C2.00010 Modifying atom-surface vDW interactions with light

ALEX CRONIN, VINCENT LONIJ, University of Arizona, JOHN PERREAULT, JILA — Electromagnetic radiation can modify van der Waals interactions. We predict how the atom-surface interaction potentials should depend on light frequency, intensity, and polarization. We also present progress towards observing this effect with an experiment based on atom diffraction from a nanograting that is illuminated by a laser.

4:18PM C2.00011 Electron Interferometry with Nanogratings

BEN MCMORRAN, ALEX CRONIN, University of Arizona — We present an electron interferometer based on near-field diffraction from two nanostructure gratings. Lau fringes are observed with an imaging detector, and revivals in the fringe visibility occur as the separation between gratings is increased from 0.2 to 2.7 mm. The oscillations in visibility depend predictably on the wavelength of incident electrons. This verifies that 5 keV electrons diffracted by nanostructures remain coherent after propagating farther than the Talbot length, and proves that a Talbot-Lau interferometer for electrons can be built with nanostructure gratings. Distorted fringes due to a phase object are used to demonstrate an application for this new type of electron interferometer.


Wednesday, June 6, 2007 1:30PM - 3:54PM –
Session C3 GEC Session: Nanoplasmas
TELUS Convention Centre Glen 201-203

1:30PM C3.00001 Experimental investigations of reactions in plasma etching of nanometer size structures

VINCENT DONNELLY, University of Houston — As the size of features on semiconductor integrated circuits becomes ever smaller, patterning and pattern transfer processes must keep pace. Plasma etching is the only viable pattern transfer method today and it is likely to remain so in the foreseeable future. Selective etching of the silicon substrate or thin films results from the synergistic reactions of normal incidence positive ions and a non-directional flux of reactive neutrals. When considering the minimum feature size that can be replicated by plasma etching, unfortunately, several fundamental limitations appear to be looming. These include dimensions that do not scale with feature size: the depth of the disordered layers that form at the bottoms and sides of features, the thickness of protective layers that prevent the sides of features from eroding, and line edge roughness. In addition, an unprecedented control of the plasma etching process will be required, calling for a similar amount of control over the concentrations of plasma species, which in turn will require a high degree of control of the nature of the plasma reactor walls. This talk will review experimental studies from this and other laboratories that explore some of these issues in plasma-surface interactions at the substrate and at the chamber walls.

2:06PM C3.00002 Plasma-particle interactions and their role in nanocrystal formation in plasmas

UWE KORTSHAGEN, University of Minnesota — Nonthermal plasmas have recently been demonstrated to be capable sources of nanocrystals with some unique properties. The negative charge of particles acquired in a plasma strongly reduces particle agglomeration. Moreover, particles in plasmas are selectively heated by electron-ion and hydrogen recombination at the particle surface, heating the particles to temperatures that exceed the gas temperature by several hundreds of Kelvin. This property makes nonthermal plasmas uniquely suited for the synthesis of nanocrystals of covalently bonded materials, such as silicon, which require high temperatures for crystalization. Several plasma processes for the synthesis of silicon and germanium nanocrystals of different sizes and morphologies are discussed. The plasma properties are assessed with capacitive probes and emission spectroscopy. The particle density and size evolution in the plasma is studied via polarization-sensitive laser light scattering. Based on the experimentally determined plasma properties, the plasma-particle interactions are analyzed and their influence on the particle formation is discussed. Finally, several examples for the applications of plasma-synthesized nanocrystals are presented.

This work is supported by NSF under award CBET-0500332 and CMMI-0556163. This work is also supported in part by the MRSEC Program of the National Science Foundation under Award Number DMR-0212302.
2:42PM C3.00003 Plasma Etching of Nano-Scale Features. YING ZHANG, IBM T. J. Watson Research Center, Yorktown Heights, NY 10598, USA — As the technology moving to deep nanometer regime, patterning nano-scale semiconductor features with precision imposes many new challenges for plasma etching. Two of the challenges are evidently critical. One of the challenges is that as the sizes of nano-scale features shrinking down to the sub-10nm regime, plasma etching seems to approach to its ‘limits’ in unprecedented ways. For instance, one may face the question of what is the smallest hole can be actually etched by plasmas. Another challenge is the precision controllability of nano-scale feature pattern transferring as the features sizes, masks materials and thickness being all shrinking down to the molecular cluster dimensions. In this paper, we summarize the recent results of studying plasma etching of true nano-scale features using variety of nano-scale patterns and masks, diblock copolymer (similar to resist) self assembled nano holes and lines and self-assembled organosilicate (similar to silicon oxide) nano patterns. Using samples patterned with arrays of nano hole or nano line dimensions in the range from 25nm down to sub-10nm, we studied plasma etching characteristics and challenges for transferring nano-scale patterns into different materials (silicon, and silicon dioxide) in different plasma chemistries and process conditions. By varying the dimensions and thickness of masks, the characteristics of aspect ratio dependent etching ‘true’ etching limits due to the sizes of sub-25nm nano-scale features were studied. The impacts and challenges of mask selectivity and line edge roughness (LER) to transfer sub-25nm patterns will be reviewed. A few proposed limiting factors of current etching tooling, underlying principles of different parameters, and processing parameters and their advantage and drawback to etching nanometer scale features will also be discussed.

3:18PM C3.00004 Nanoscule Challenges in Plasma-Surface Interactions. DAVID GRAVES, University of California at Berkeley — Plasmas have been used for many years in various thin film processing technologies to transfer patterns via etching. Recent developments in semiconductor device manufacturing have increased plasma etch challenges. The historic shrink in critical dimension continues apace. New photoresist materials tend to etch faster and roughen more than previous resists. Important plasma etch goals includes controlling critical dimensions, maintaining high rates of etching, minimizing effects of local patterns, minimizing damage and contamination, and maintaining uniformity across 300 mm wafers. To achieve these goals, etch tool manufacturers often must explore a significant fraction of the enormous parameter space available in plasma etch tools, but with little guidance from fundamental understanding. In particular, a key problem is controlling feature shape with nanometer-scale precision. In this talk, I will describe results that focus on the principles of plasma-surface interactions, including the nature of the plasma-modified near-surface region, intrinsic nanoscale fluctuations during etching and the nature of plasma-induced surface roughness in organic polymers.

Wednesday, June 6, 2007 1:30PM - 3:54PM

Session C4 Quantum Computing TELUS Convention Centre Glen 206

1:30PM C4.00001 One-way quantum computing in optical lattices with many atom measurements. TIMOTHY FRIESEN, DAVID FEDER, University of Calgary — With one-way quantum computation universality can be achieved using only single qubit measurements on a highly entangled state, known as a cluster state. By manipulating ultracold atoms in optical lattices it is possible to efficiently generate large, many-qubit cluster states. Although this approach to one-way computing is promising, the small spacing between lattice sites severely restricts our ability to sequentially measure the states of individual atoms by external lasers, a necessary condition for universal computing. Working within the limitations of current technology we must generally consider many atom measurements. We have developed a deterministic protocol for one-way quantum computing based on many atom measurements on an optical lattice cluster state, with only polynomial classical overhead. Our scheme opens the way toward concrete experimental quantum computing in neutral atom systems.

1:42PM C4.00002 Entangling operations and rapid measurement of atomic clock-state qubits for violating Bell inequalities. RENÉ STOCK, NATHAN S. BACCOCK, Institute for Quantum Information Science, University of Calgary, MARK G. RAIZEN, Center for Nonlinear Dynamics and Department of Physics, University of Texas, Austin, BARRY C. SANDERS, Institute for Quantum Information Science, University of Calgary — Optical clock-transitions such as the ones in Ytterbium/Strontium and Cesium are prime candidates for encoding qubits for quantum information processing applications due to very low decoherence rates. In this work, we investigate the challenges involved in using these prime candidates. We devise entangling operations for atoms trapped in optical tweezers, as well as determine the feasibility of rapid qubit rotation and measurement of qubits encoded in these desirable low-decoherence clock transitions. We propose ultracold collisions for entangling operations and multi-photon transitions for fast rotation of qubits, followed by ultrafast readout via resonant multiphoton ionization. The rapid control of atomic qubits is crucial for high-speed synchronization of quantum systems, but is also of interest for tests of Bell inequalities. We investigate rapid measurement of clock-state qubits in the context of a Bell inequality test that avoids the detection loophole in spacelike separated entangled qubits.

1:54PM C4.00003 Quantum Simulators, Spin Systems, and Trapped Ions. WARREN LYBARGER, Los Alamos National Laboratory / UCLA, JOHN CHIAVERINI, ROLANDO SOMMA, DAVID LIZON, W. ROBERT SCARLETT, MALCOLM BOSHIER, DANA BERKELAND, Los Alamos National Laboratory — Many-quantum-spin systems cannot be efficiently simulated on classical computers as they require exponentially large resources. Yet many such systems can be simulated efficiently with quantum simulators (QS) that do not require universal control like quantum computers. Following the work of Porras and Cirac [Phys. Rev. Lett. 92, 207901-1 (2004)] we discuss current experimental efforts at Los Alamos to implement a QS for Ising-like and Heisenberg-like models with trapped ion qubit “spins”. The states of the QS follow nearly the same equations of motion as the systems of interest, and unlike with real materials, the experimenter has the advantage of direct access to and control over the spins. We will discuss progress towards proof-of-principle investigations of two-ion simulations in a single-well trap, in which we use state-selective optical forces to induce ion-ion interactions.

2:06PM C4.00004 Sympathetic cooling of a atom in a transported trap via superfuid immersion, preserving quantum information. DAVID HAYES, University of New Mexico, IVAN DEUTSCH, UNM TEAM — We investigate the possibility of using sympathetic cooling via super-fluid immersion in order to suppress diabatic transitions in a system governed by a time-dependent Hamiltonian. A simple model is constructed in order to study how to store quantum information can be stored in the nuclear spin of a group-II atom that is trapped in a harmonic oscillator, while it is traveling at a constant velocity inside of a stationary BEC. While the motion of the trap acts to heat the atom in the trap to higher vibrational levels, the motion of the trapped atom creates excitations in the BEC and carries the energy away in the form of phonons and decreases the effective heating. Quantum information is preserved as the nuclear spin is decoupled from all other degrees of freedom.

2:18PM C4.00005 Bright Source of Cold Ions for Surface-Electrode Traps. MARKO CETINA, ANDREW GRIER, Department of Physics, MIT Center for Ultracold Atoms, JONATHAN CAMPBELL, Department of Physics, United States Military Academy, ISAAC CHUANG, Department of Physics and Department of Electrical Engineering, MIT Research Laboratory of Electronics, VLADAN VULETIC, Department of Physics, MIT Center for Ultracold Atoms — We produce large numbers of low-energy ions by photoionization of laser-cooled atoms inside a surface-electrode-based Paul trap. The isotope-selective trap loading rate of 4 x 10^5 ¹⁷⁴Yb⁺ ions/s exceeds that attained by photoionization (electron impact ionization) of an atomic beam by four (six) orders of magnitude. Our high loading rate could enable rapid, isotope-selective loading of large ion trap arrays for use in quantum computing or atomic clocks. The ions are confined in the same spatial region as the laser-cooled atoms, which will also allow experimental investigation of the interactions between cold ions and cold atoms. ¹This work was supported in part by the NSF Center for Ultracold Atoms.
where the electrodes are located in a single plane and the ions are confined above this plane.

SHIGA, D.J. WINELAND, Time and frequency division, NIST, Boulder CO, USA — We confine individual atomic ions in rf Paul traps with a novel geometry.

URBAN, TODD JOHNSON, THOMAS HENAGE, LARRY ISENHOWER, MARIE DELANEY, a universal two-qubit entangling gate. These demonstrations provide important tools for quantum information processing and simulation of condensed matter.

40 micrometers above the planar electrodes and their heating rate is low enough to make the traps useful for quantum information processing.

frequency or polarization upon decay to their respective ground states. Preliminary results have been achieved with this technique using trapped band.

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nuclear spin leads to ground state hyperfine splitting, where the same excitation method would create optical qubits and ion-photon entangled states.

This work was supported by the NSF and ARO-DTO.

2:54PM C4.00008 Spin exchange in a double-well optical lattice for a $\sqrt{\text{SWAP}}$ gate, PATRICIA LEE, NIST, MARCO ANDERLINI, BENJAMIN BROWN, JENNIFER SEBBY-STRABLEY, WILLIAM PHILLIPS, TREY PORTO. We report the observation of coherent spin-exchange between pairs of atoms in a double-well optical lattice, from which a $\sqrt{\text{SWAP}}$ gate can be constructed. First, we perform qubit rotations selectively to atoms in either side of the double well to prepare pairs of qubits in the initial state. Each pair of neighboring atoms are then brought together in a single well and entangled through controlled coherent collisions. The "exchange blockade" arising from the symmetry of identical particles results in $\sqrt{\text{SWAP}}$, a universal two-qubit entangling gate. These demonstrations provide important tools for quantum information processing and simulation of condensed matter systems. We will also discuss how they can be extended to a scalable system for quantum computation.

3:06PM C4.00009 Excitation and interaction of Rydberg states in optical dipole traps, ERICH URBAN, TODD JOHNSON, THOMAS HENAGE, LARRY ISENHOWER, MARIE DELANEY, DENIZ YAVUZ, THAD WALKER, MARK SFAFFMAN, University of Wisconsin Madison — We present recent progress in two-photon excitation of Rydberg levels with nuclear spin leads to ground state hyperfine splitting, where the same excitation method would create optical qubits and ion-photon entangled states. The importance of these results for implementation of neutral atom quantum gates using dipole-dipole interactions of Rydberg states will be discussed.

3:18PM C4.00010 Femtosecond optical excitation of trapped barium ions, N. KURZ, M.R. DIETRICH, R. BOWLER, C.T. HOWELL, V. MIRGON, J.S. SALACKA, C. SHU, L. WANG, B.B. BLINOV, UNIVERSITY OF WASHINGTON DEPARTMENT OF PHYSICS SCIENCE — Ion-photon entanglement and the remote entanglement of trapped ions are crucial building blocks of several proposed quantum computing architectures. The creation and detection of single photons from the trapped ions is a fundamental step in this process. Ultrafast laser pulses with an optical bandwidth broad enough to coherently excite both hyperfine levels of the ground state can be used to create optical qubit photons differentiable by their frequency or polarization upon decay to their respective ground states. Preliminary results have been achieved with this technique using trapped $^{139}\text{Ba}^+$ ions, which displays Rabi oscillations between $S_{1/2}$ and $P_{1/2}$ states driven by near-resonant 400 fs pulses at 455 nm. We plan to use the odd isotope ($^{137}\text{Ba}^+$) whose nuclear spin leads to ground state hyperfine splitting, where the same excitation method would create optical qubits and ion-photon entangled states.

3:30PM C4.00011 Microfabricated surface-electrode ion traps for scalable quantum information processing, S. SEIDELIN, J. BRITTON, J. CHIaverini, R. REICHEL, J.J. BOLLINGER, D. LEIBFRIED, J.H. WESENBERG, R.B. BIAKESTAD, R.J. EPSTEIN, J.M. AMINI, K.R. BROWN, J.P. HOME, D.B. HUME, W.M. ITANO, J.D. JOST, E. KNILL, C. LANGER, N. KURZ, M.R. DIETRICH, N. KURZ, M.R. DIETRICH, R. OZERI, N. SHIGA, D.J. WINE LAND. Time and frequency division, NIST, Boulder CO, USA — We confine individual atomic ions in rf Paul traps with a novel geometry where the electrodes are located in a single plane and the ions are confined above this plane. These devices are realized with simple fabrication procedures, making them potentially scalable for quantum information processing using large numbers of ions. For traps fabricated from gold on fused quartz, the ions are 40 micrometers above the planar electrodes and their heating rate is low enough to make the traps useful for quantum information processing.

1This work was supported by the NSF and ARO-DTO.

3:30PM C4.00011 Microfabricated surface-electrode ion traps for scalable quantum information processing, S. SEIDELIN, J. BRITTON, J. CHIaverini, R. REICHEL, J.J. BOLLINGER, D. LEIBFRIED, J.H. WESENBERG, R.B. BIAKESTAD, R.J. EPSTEIN, J.M. AMINI, K.R. BROWN, J.P. HOME, D.B. HUME, W.M. ITANO, J.D. JOST, E. KNILL, C. LANGER, N. KURZ, M.R. DIETRICH, N. KURZ, M.R. DIETRICH, R. OZERI, N. SHIGA, D.J. WINE LAND. Time and frequency division, NIST, Boulder CO, USA — We confine individual atomic ions in rf Paul traps with a novel geometry where the electrodes are located in a single plane and the ions are confined above this plane. These devices are realized with simple fabrication procedures, making them potentially scalable for quantum information processing using large numbers of ions. For traps fabricated from gold on fused quartz, the ions are 40 micrometers above the planar electrodes and their heating rate is low enough to make the traps useful for quantum information processing.

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present our preliminary design for a cooler Penning trap which can accommodate both electron and proton cooling. We will also present simulations of the cooling process, including the potentially detrimental effects of radiative, dielectronic, and three-body recombination. We will also present our consideration of sympathetic cooling with initially cold protons provided by a cold ion source. We will discuss the extraction of ions from the EBIT charge breeder and the measurement of the decay rate of the negative ion of positronium. Highly charged ions (HCI) extracted from the EBIT charge breeder will likely have a temperature of tens of eV/charge or more, too high for direct injection into the trap. One possible route is electron cooling, where the HCI interact with a cloud of electrons, which self-cool via the emission of synchrotron radiation. Measurement of the decay rate of the negative ion of positronium (Ps⁻) represents the simplest three-body system with a bound state. Its constituents are stable, point-like particles, and it is essentially free from perturbation by strong interaction effects. Together with the rather unique mass ratio, these properties make the positronium an interesting object for studying the quantum-mechanical three-body problem. We present a new determination of the decay rate, using a beam-foil method and a stripping-based detection technique. The measured value of $\Gamma = 2.089(15) \text{ns}$ is a factor of six more precise than the previous experimental result, and there is excellent agreement both with the latter and with the theoretical value.

**1:42PM C5.00002 Excited, Resonant, and Unnatural Parity States of Positronic Atoms and Ions**

Michael W. J. Bromley, Department of Physics, San Diego State University, Jim Mitroy, Faculty of Technology, Charles Darwin University, Kalman Varga, Department of Physics and Astronomy, Vanderbilt University — Calculations have demonstrated that 11 neutral atoms can bind positrons. We report on configuration interaction (CI) calculations that have demonstrated the existence of a $^2P$ excited state of $e^+Ca$, which consists predominantly of a positronium (Ps) cluster orbiting the Ca⁺ ion in the J = 1 partial wave. This raises the possibility of detecting the formation of positronium bound states from an optical transition to the ground ($^2S$) $e^+Ca$ state. The $^{13}Me$ system is shown to lack an equivalent excited state, however, by extracting phase shifts from CI pseudostate energy shifts, we show that the system has a low-energy $p$ shape resonance. Finally, CI and stochastic variational method calculations of annihilation suppressed, unnatural parity $^{1,2,3,4}S_0^-$ states of PsH, LiPs, NaPs, and KPs are reported. The LiPs system is shown to have an $^2P$ excited state.

**1:30PM C5.00001 Measurement of the Decay Rate of the Negative Ion of Positronium (Ps⁻)**

G. Winner, University of Manitoba, Winnipeg, Canada, F. Fleischer, K. Degreif, M. Lestinsky, F. Plegen, D. Schwalb, Max-Planck-Institute for Nuclear Physics, Heidelberg, Germany, V. Liechtenshtern, Kurchatov Institute, Moscow, Russia — Consisting of two electrons and a positron, the negative ion of positronium (Ps⁻) represents the simplest three-body system with a bound state. Its constituents are stable, point-like particles, and it is essentially free from perturbation by strong interaction effects. Together with the rather unique mass ratio, these properties make the positronium an interesting object for studying the quantum-mechanical three-body problem. We present a new determination of the decay rate, using a beam-foil method and a stripping-based detection technique. The measured value of $\Gamma = 2.089(15) \text{ns}$ is a factor of six more precise than the previous experimental result, and there is excellent agreement both with the latter and with the theoretical value.

**1:28PM C5.00005 A Cooler Trap for the TITAN On-line Trapping Facility at TRIUMF**

G. Winner, Z. Ke, W. Shi, S. Toews, University of Manitoba, Winnipeg, Canada, D. Dilling, V. Ryzkov, TRIUMF, Vancouver, Canada — The TITAN ion trap facility currently under construction at TRIUMF’s ISAC will provide for the first time highly charged radioactive ions for precision mass measurements. Highly charged ions (HCI) extracted from the EBIT charge breeder will likely have a temperature of tens of eV/charge or more, too high for direct injection into the precision Penning trap mass spectrometer. We are currently developing an intermediate Penning cooler trap to pre-cool the HCI prior to the mass measurement. One possible route is electron cooling, where the HCI interact with a cloud of electrons, which self-cool via the emission of synchrotron radiation in the strong magnetic field of the Penning trap; another possibility is sympathetic cooling with initially cold protons provided by a cold ion source. We will present simulations of the cooling process, including the potentially detrimental effects of radiative, dielectronic, and three-body recombination. We will also present our preliminary design for a cooler Penning trap which can accommodate both electron and proton cooling.
2:30PM C5.00006 Photoionization loading of barium ion traps. • ADAM STEELE, LAYNE CHURCHILL, PAUL GRIFFIN, MICHAEL CHAPMAN, Georgia Institute of Technology — We demonstrate a simple and effective technique for photoionization loading barium ions into a linear trap. Photoionization allows isotope selectivity, greater loading efficiency, and eliminates the charging of insulators in the trapping region, typical of electron impact ionization. Two-step photo-ionization of barium is accomplished using an intercombination line in neutral barium (5s^2 S_0 \rightarrow 6s6p^2 P_1, \lambda = 791 nm) followed by excitation above the ionization threshold using a nitrogen gas laser (\lambda = 337 nm). Isotopic selectivity is achieved by near doppler-free excitation of the triplet 6s6p^2 P_1 state. Application of the technique to a barium ion trap cavity QED experiment will be discussed.

2:42PM C5.00007 The Development of a Passive Electrostatic Electron Recycling System (ERS). • DAVID TESSIER, YING NIU, DOMINIC SECCOMBE, TIMOTHY REDDISH, University of Windsor, Canada, AARON ALDERMAN, BEN BIRDSEY, PETER HAMMOND, University of Western Australia, Australia, FRANK READ, University of Manchester, U.K. — The development of a completely new type of electron spectrometer, an “Electron Recycling Spectrometer” (ERS) is described in which low energy (<~50 eV) electrons are passively stored in a ‘desktop’ sized ring. The orbital path for the electrons is 0.65 m long with a race-track geometry and is defined through the application of design voltages to two series of cylindrical electrostatic lenses inserted between two identical hemispherical deflector analyzers. The ERS design concept exploits the very low scattering cross sections in electron-molecule collisions, where the majority of electrons do not interact with the gaseous target. Unscattered electrons are collected, passed back through the ERS for another collision opportunity in the interaction region - i.e. they are “recycled” so that each electron generated in the electron source may undertake multiple passes through the interaction region. Initial results will be presented which demonstrate that the electron beam undergoes up to ~1000 orbits in a time of ~250 μs. The design of the system is likely to enable the storage at low kinetic energy of any type of non-relativistic charged particle, including positrons, polarized electrons, and positive & negative ions.

2:54PM C5.00008 A miniature differential atomic magnetometer based on a diverging laser beam. • ELEANOR HODBY, ELIZABETH DONLEY, JOHN KITCHING, Time and Frequency Division, NIST, 325 Broadway, Boulder, CO 80305, USA — We demonstrate a novel atomic magnetometer that uses differential detection of the spatially diverging components of a light field to monitor the Larmor precession frequency of atoms in a thermal vapor [1]. The design is implemented in compact form with a micromachined alkali vapour cell and a naturally divergent light field emitted by a vertical cavity surface emitting laser, which serves to both optically pump the atoms and measure the transverse polarization. The size of the core physics assembly is < 1cm^3. The simplicity of the experimental design makes it ideally suited for highly miniaturized implementations and wafer-level mass production. Operating the magnetometer in differential mode cancels common-mode noise and improves the sensitivity by a factor of 26 over single-channel operation. Finally, we suggest ways in which the current sensitivity of 28 pT/√Hz may be improved further without sacrificing size or simplicity. [1] E. Hodby et al. To be submitted.

3:06PM C5.00009 A portable ultrasensitive atomic magnetometer for biomagnetic measurements. • ROBERT WYLLIE, ZHIMIN LI, Department of Physics, University of Wisconsin-Madison, RONALD WAKAI, Department of Medical Physics, University of Wisconsin-Madison, NICHOLAS PROITTLE, PETER COOK, THAD WALKER, Department of Physics, University of Wisconsin-Madison — We present a portable Rb cell atomic magnetometer suited for biomagnetic measurements. Working in the spin-exchange relaxation free regime, we demonstrate an initial white noise floor of 60 fT/√Hz. We show an adult magnetic cardiogram and demonstrate the feasibility of extending our measurements to fetal MCG. Based on previous experiments the noise floor can be further reduced by parametrically modulating the z-magnetic field, which also allows for the simultaneous measurement of the x and y field components using a single probe beam [1]. We will present the simple conversion of the magnetometer to a gravitometer to study g anomalies.

3:18PM C5.00010 Study of surface interactions of spin polarized Rb atoms in coated cells using the evanescent wave magnetometer. • K.F. ZHAO, M. SCHADEN, Dept. of Phys, Rutgers University - Newark, Z. WU, Rutgers University - Newark — We describe a new method of studying surface interactions of spin polarized rubidium atoms on silicone-coated Pyrex glass surfaces by operating the evanescent wave magnetometer in an inhomogeneous magnetic field. By analyzing the lineshape of the magnetic resonances using a theory we developed, we can estimate various parameters that characterize the surface interactions. Most interestingly, the lineshape is very sensitive to the phase shift of the Rb atom while it is on the surface. We measured for typical Surfasis(silicone) coated cells.

3:30PM C5.00011 Spin-Exchange Optical Pumping of Solid Alkali Compounds. • BRIAN PATTON, KIYOSHI ISHIKAWA, YUAN-YU JAU, WILLIAM HAPPER, Princeton University — We demonstrate enhancement of the 1^3S-Cs nuclear polarization in a film of cesium hydride which has been placed in contact with an optically pumped cesium vapor. The maximum observed polarization at 9.4 T and 137°C is roughly 4 times the equilibrium polarization, but higher magnetizations are possible at lower magnetic fields. In an attempt to determine the mechanism of spin transfer from the alkali vapor to the solid, we have performed this experiment at intermediate magnetic fields (1-2 tesla) while pumping different optical transitions in the vapor. We will discuss the predicted spin current to the CsH layer in this regime of partial hyperfine decoupling and propose new methods for generating even higher polarizations in the solid. Potential applications of this technique will be mentioned as well as its extension to other compounds.

3:42PM C5.00012 Intracavity Optogalvanic Spectroscopy (ICOGS) • ERHAN ILKimen, OZGUR DOGRU, DANIEL MURNICK, Rutgers University, Newark, NJ 07102 — Optogalvanic spectroscopy is a powerful technique for isotopic ratio analysis of CO2. Isotopic lasers in resonance with specific molecular transitions in a RF glow discharge provide high specificity. Periodically modulated laser beam changes the population densities of the specific excited molecules thus changing the impedance of the discharge, which then can be detected as voltage change across the electrodes. The optogalvanic signal is linear in path length and laser intensity providing a way to achieve high sensitivity. Earlier external cell studies have shown the limit of detection of 14C/12C ratio to be of the order of ~10^-9. It is now shown that placing the analyte cell directly into a 14CO2 laser cavity greatly enhances the sensitivity — by about 10^6 which enables detection of trace amounts of 14CO2 molecules with high signal to noise ratios. This huge improvement in sensitivity from the earlier studies is believed to be due to high internal laser power (~50W) and increase in interaction length of the laser photons with the excited molecules. The effective interaction length is of the order of the single mode laser coherence length. Unlike in intracavity laser absorption spectroscopy, the ICOGS signal does not change the laser output.

1Research supported by the NIH and Merck Research Laboratories.
Wednesday, June 6, 2007 1:30PM - 4:06PM
Session C6 Spectroscopy of Molecules and Molecular Clusters
TELUS Convention Centre Oldie Scotch Room

1:30PM C6.00001 Observation of the ‘missing’ polar OCS dimer. MAHIN AFSHARI, MEHDI DEHGHANI, ZIAD ABUSARA, NASSER MOAZZEN-AHMADI, Department of Physics and Astronomy, University of Calgary. ROBERT MCKELLAR, Steacie Institute for Molecular Sciences, National Council of Canada. LASER SPECTROSCOPY TEAM — The lowest energy, non-polar isomer of (OCS)₂ has long been known from infrared spectroscopy, while the polar form has only been deduced from qualitative beam ‘refocusing’ experiment. We have observed a new infrared band at 2069.3 cm⁻¹ and assigned to the long-anticipated polar isomer of OCS dimer, helping to explain apparent discrepancies among earlier studies. Reported data which have been confirmed by direct observation of the rotational spectrum of polar OCS dimer, should motivate new theoretical work on the energies of OCS dimer isomers and interconversion energy barriers. OCS dimer is now one of the rare weakly bound clusters to have more than one isomer observed in high resolution spectroscopy.

1National Science and Engineering Research Council of Canada

1:42PM C6.00002 The structure of OCS tetramer from infrared laser spectroscopy. MEHDI DEHGHANY, MAHIN AFSHARI, ZIAD ABUSARA, Author, NASSER MOAZZEN-AHMADI, author and supervisor, A.R.W. MCKELLAR, Author and collaborator, A.R.W. MCKELLAR COLLABORATION — The motivation for studying weakly bound complexes is building a bridge between the gas and condensed phase. There are many condensation pathways that can be taken, owing to exponentially increasing number of isomers with cluster size. The factors that determine which of these are preferred and why are not well understood. High resolution infrared laser spectroscopy has been used for the first time to determine the structure of OCS tetramer. We observe a non-planar structure in which all four monomers are approximately parallel. The spectra are best described as an asymmetric top with an accidental spherical top structure. The spectrometer and analysis of data will be presented.

2:06PM C6.00004 Cyanoacetylene-doped ortho-hydrogen and para-hydrogen clusters studied using rotational spectroscopy. JULIE MICHAUD, WOLFGANG JÄGER, Department of Chemistry, University of Alberta, Edmonton, AB T6G 2G Canada — A high-resolution Fourier transform microwave spectrometer was used to measure the rotational spectra of the orthoH₂ – HCCCN and paraH₂ – HCCCN dimers as well as larger (orthoH₂)₂ – HCCCN and (paraH₂)₂ – HCCCN van der Waals clusters (N = 2 and greater). To generate the clusters, low concentrations of HCCCN and H₂ (normal or enriched paraH₂) in helium are used at pressures up to 70 atm. The helium supersonic jet expansion into the spectrometer cavity/sample produces a collection free environment where the clusters are stabilized and studied. Varying the backing pressure, sample concentrations and/or nozzle temperature can control cluster size. The doped paraH₂ clusters are of particular interest because paraH₂ is suspected to exhibit the bulk property of superfluidity, similar to ⁴He. The study of the successive solvation of HCCCN with H₂ molecules may provide evidence for superfluidity in doped H₂ clusters.

2:18PM C6.00005 High resolution infrared spectra of helium clusters doped with carbon dioxide or nitrous oxide. ROBERT MCKELLAR, National Research Council of Canada — Infrared laser spectroscopy is used to study low temperature (~0.2 K) helium clusters in a pulsed supersonic jet expansion. The clusters are doped with a probe molecule (CO₂ or N₂O) whose vibration-rotation spectrum is observed as a function of cluster size. Our previous work on smaller clusters (N < 20) is extended to larger clusters (N ~ 70) using a new apparatus with a skimmed jet nozzle. Various isotopes are studied in order to make the assignment of cluster size more secure, including the asymmetric species ¹⁶O₂¹⁵C₂O. The cluster rotational parameters exhibit broad oscillations, similar to those recently observed in He₂ - OCS, which are related to the formation of superfluid helium solvation shells around the probe molecule.

2:30PM C6.00006 Spectroscopic and ab initio study of the open-shell Xe-O₂ van der Waals Complex. QING WEN, WOLFGANG JÄGER, Department of Chemistry, University of Alberta — Rotational spectra of the open-shell Xe-O₂ van der Waals complex were recorded using a pulsed-nozzle Fourier transform microwave spectrometer. Magnetic hyperfine structure arising from the earth's magnetic field is observed as a function of cluster size. Our previous work on smaller clusters (N ∼ 20) is extended to larger clusters (N ∼ 70) using a new apparatus with a skimmed jet nozzle. Various isotopes are studied in order to make the assignment of cluster size more secure, including the asymmetric species ¹⁶O₂¹⁵C₂O. The cluster rotational parameters exhibit broad oscillations, similar to those recently observed in He₂ - OCS, which are related to the formation of superfluid helium solvation shells around the probe molecule.

2:42PM C6.00007 Intermolecular Hydrogen Bonding Effect on the VA and VCD Spectra of Lactic Acid in Water and in Methanol: Experimental and DFT Studies. MARTIN LOSADA, HA TRAN, YUNJIE XU. University of Alberta — Understanding the structure, stability and formation of intermolecular H-bonded complexes involving chiral molecules on the molecular level is of crucial importance in life sciences. Carboxylic acids are well known for their strong intermolecular associations. Lactic acid (LA) is studied using vibrational absorption (VA) and vibrational circular dichroism (VCD) spectroscopic techniques to examine the effect of dimerization. Theoretical results indicate that for LA in CDCl₃ solution, a complex equilibrium exists between the monomers and dimers. Furthermore, VCD spectroscopy was used to probe the solute-solute and solute-solvent H-bonding interactions of LA-water and LA-methanol complexes, with n = 1, 2, 3, using both B3PW91/6-311++G(d) and B3LYP/6-311+G(d,p) levels of theory. Some of these clusters were also investigated at the B3LYP/cc-pVTZ level. Detailed spectral simulations were performed in order to understand the dependence of the VA and VCD spectra on the specific binding characters. Three solvent models were exploited to evaluate solute effects; a pure implicit continuum approach, a pure explicit model with up to three solvent molecules, and a combined approach.
2:54PM C6.00008 Microwave spectroscopic studies of molecular recognition: Analysis of diasteromeric interactions between ethane and oxirane derivatives. NICOLE BORHO, YUNJIE XU, University of Alberta — High resolution microwave spectroscopy complimented by ab initio calculations has been used to elucidate the diasteromeric interactions in a set of small model complexes. Ethanol, a transient chiral alcohol, was combined with oxirane (achiral), methyl-oxirane\(^1\) (1 stereocenter) and trans-2,3-dimethyloxirane (2 stereocenters) to form hydrogen-bonded 1:1 complexes. The rotational constants of two conformers of ethanol--oxirane, six conformers of ethanol--methyl-oxirane and three conformers of ethanol--trans-2,3-dimethyloxirane have been determined and the relative stability order of the conformers has been established. The dependence of the observed intensity on pressure, nozzle temperature and different carrier gases has been investigated for the case of ethanol--trans-2,3-dimethyloxirane to give a first insight into the kinetical and thermodynamical influence on the formation of different conformers. The step-by-step methyl addition to oxirane helps to unravel the diasteromeric interactions at play via analysis of the subtle energy differences between each set of conformers, allowing for a detailed understanding of molecular recognition in this benchmark system.

\(^{1}\)Nicole Borho, Yunjie Xu, Angew. Chem., 2006, (VIP paper, Published Online: 17 Nov 2006, DOI: 10.1002/anie.200603809).

3:06PM C6.00009 A New VISTA on the Infrared Spectrum of Ammonia in the 1.5 µm Region: Assignment of Combination Bands of \(^{14}\)NH\(_3\) and \(^{15}\)NH\(_3\) by Isotopic Shift Finger printing. RONALD LEES, Centre for Laser, Atomic and Molecular Sciences (CLAMS) and Department of Physics, University of New Brunswick, Saint John, NB, Canada E2L 4S3, LI LI, LI-HONG XU, CLAMS, University of New Brunswick — The infrared spectrum of ammonia in the 1.5 µm region contains a complex mixture of vibrational combination and overtone bands. By comparing spectra of \(^{14}\)NH\(_3\) and \(^{15}\)NH\(_3\) recorded with a tunable diode laser spectrometer, we have been able to implement a Vibrational Isotopic Shift Technique for Assignment (VISTA) in which isotopic shift fingerprinting (ISF) is used to classify spectral lines into their respective absorption bands. We have thereby been able to identify numerous lines belonging to the strong \(v_9+2v_4\) band for \(^{14}\)NH\(_3\), extend assignments for previously known \(^{14}\)NH\(_3\)bands, and simultaneously assign the corresponding bands for \(^{15}\)NH\(_3\).

3:18PM C6.00010 A global frequency analysis of data in the four lowest vibrational states of ethane, LEILAR BORVAYEH, NASSER MOAZZEN-AHMAIDI, Department of Physics and Astronomy, University of Calgary — The \(v_9\) fundamental band of ethane occurs in the 12 µm region. It is the strongest band of ethane in a terrestrial window and is commonly used to determine ethane’s abundance in the atmospheres of the Jovian planets and comets, and to determine their temperature. The \(v_9 + v_9 - v_4\) band occurs in the same region; neither can be analyzed as an isolated band, since both are embedded in the torsional bath of the ground vibrational state. Precise and accurate absolute intensities of these bands are crucial for correct interpretation of recent Cassini observations of ethane spectra in the atmospheres of Saturn and Titan. Although, our group has carried out a satisfactory frequency analysis of the \(v_9\) fundamental, a complete analysis of \(v_9 + v_9 - v_4\) is hampered due to an interaction with the \(v_{12}\) fundamental. This fundamental vibration is infrared inactive. It is also very weakly Raman active. To access this vibrational state, we have obtained a high resolution Fourier transform spectrum of the weak \(v_{12} - v_9\) band using a Bruker IFS120HR. In this talk, I will describe a global frequency analysis of data including the four lowest vibrational states of ethane.

3:30PM C6.00011 Ab initio and Rotational Spectroscopic Study of Propylene Oxide – (Water)\(_{N=2/3}\) Complexes, ZHENG SU, YUNJIE XU, University of Alberta — Water is the principal constituent of the environment for all living organisms. Nearly all biological molecules required for life are chiral. Therefore the studies of the solvation of chiral molecules in water are of fundamental importance to life science. In this work, we report ab initio and rotational spectroscopic studies of the hydrogen bonded propylene oxide (PO) – \((\text{H}_2\text{O})\)\(_{N=2/3}\) clusters, which is a continuing study from our success on PO with one water molecule in the gas phase. The sequential complexation of PO with a few water molecules is a significant step towards understanding the solvation process for this simplest cyclic ether chiral molecule. Complete geometry optimizations for the PO-water complexes are carried out at the MP2 level of theory with the 6-311++G(d,p) basis set using the GAUSSIAN03 software package. The calculated rotational constants and dipole moment components are used to aid the initial spectroscopic investigations. By systematically increasing the pressure, attachment of more water molecules to PO can be formed and distinguished from only one. Both experimental and theoretical results are used to extract structural and dynamic information about the complexes. The experimental analysis will in turn be used to judge the quality of the theoretical predictions and then determine the appropriate model for further calculations.

3:42PM C6.00012 Experimental determination of the Herman-Wallis factor of Q-branch Raman transitions, MICHELE MARROCCO, ENEA — Vibration-rotation interaction is crucial to the accurate understanding of spectroscopic line intensities of light molecules. The interaction is quantified by the so-called Herman-Wallis (HW) factor F [J. Chem. Phys. 23, 637 (1955)] whose calculation is debatable for Q-branch transitions. Indeed, different authors have suggested different HW factors in manifest disagreement with each other. To clarify this matter, we report on: (1) an experiment based on vibrational coherent anti-Stokes Raman spectroscopy (CARS) applied to H\(_2\) molecules, (2) an experiment based on vibrational coherent anti-Stokes Raman spectroscopy (CARS) applied to H\(_2\) molecules, (3) an experiment based on vibrational coherent anti-Stokes Raman spectroscopy (CARS) applied to H\(_2\) molecules, (4) an experiment based on vibrational coherent anti-Stokes Raman spectroscopy (CARS) applied to H\(_2\) molecules. The HW factor that justifies the experimental data is given in the work of Tipping and Bouanich [J. Quant. Spectrosc. Radiat. Transfer 71, 99 (2001)].

3:54PM C6.00013 Off-axis cavity enhanced absorption spectrometer based on a mid-infrared continuous wave quantum cascade laser, YUNJIE XU, Department of Chemistry, University of Alberta, Edmonton, Canada, RAVIRAJ KULKARNI, WAISHUN TAM, ZHENG SU, IGOR LEONOV, University of Alberta, Canada — We present the design and construction of a mid-infrared off-axis cavity enhanced absorption (OA-CEAS) spectrometer based on a cw quantum cascade laser in combination with a pulsed slit jet molecular beam expansion. A computer program was developed to automate and to synchronize the timing of the CEAS experiments with the pulsed molecular beam. The dominant source of noise in CEAS experiments arises from incomplete averaging of the cavity mode structures. The suppression of noise was accomplished by implementing the following procedures: (1) Optimize off-axis alignment to excite as many higher order transverse modes as possible. (2) Modulate the cavity length using a piezolectric actuator mounted on one of the cavity mirrors. (3) Introduce mechanical perturbation in the optical cavity to randomize the residual mode structures. (4) Optimize laser frequency speed to even cavity mode intensities. (5) Apply wavelength modulation to the laser. The CEAS experimental result measured with a static NH\(_3\) gas and with jet-cooled larger organic molecules will also be presented.

4:00PM - 4:00PM — Session D1 Poster Session I — TELUS Convention Center Macleod A, 4:00pm - 6:00pm

D1.00001 ULTRACOLD MATTER I —
D1.00002 Anomalous Recombination Rates in Ultracold Plasmas

ROBERT FLETCHER, XIANLI ZHANG, STEVEN ROLSTON, University of Maryland — Three-body recombination, one of the major loss processes in plasmas, has been studied over a range of densities and temperatures, resulting in a widely accepted expression for the three-body recombination rate that scales as $T^{-4.5}$. We present experimental measurements of Rydberg atom formation in ultracold plasmas ($T < 20K$) that calls this into question. By applying a pair of short (200 ns) microwave pulses at 2.4 GHz, we ionize and detect Rydberg atoms in a quasineutral ultracold xenon plasma without destroying the plasma. Varying the delay between the two pulses, we measure the refill rate of Rydberg atoms in the plasma. The observed rates are much larger than three-body recombination theory predicts using temperature measurements from prior experiment and simulation results. This implies that either the ultracold plasma temperature is much lower than previously thought, or currently accepted three-body recombination theory fails below $\sim$20K.

D1.00003 Electron screening and ion temperature equilibration in ultracold plasmas

ADAM DENNING, SCOTT BERGESON, Brigham Young University — The dynamics of ultracold plasmas at early times are dominated by nearest-neighbor interactions. For plasmas created from photo-ionized MOT atoms, this interaction leads to disorder-induced heating and ion temperature oscillations over time scales roughly equal to $\omega_{p}^{-1}$. The details of this heating should contain information about how the electrons shield ions during collisions. We report measurements of ion heating vs. initial electron temperature and plasma density. Under certain conditions, the time scale for disorder induced heating increases from $\omega_{p}^{-1} \sim 2$ to 5, suggesting strong electron shielding. We present a one-dimensional model to explain these observations.

D1.00004 The four body problem

SETH T. RITTENHOUSE, Department of Physics and JILA, University of Colorado, Boulder, CO 80309, NIRMAL P. MEHTA, J. P. D’INCAO, JILA, University of Colorado, Boulder, CO 80309, CHRIS H. GREENE, Department of Physics and JILA, University of Colorado, Boulder, CO 80309 — Using democratic, body fixed hyperspherical coordinates, the four fermion problem can be reduced to a set of five dimensional integrals over a physically motivated variational basis. This method accurately produces the low-lying adiabatic hyperspherical potential curves. The details of our method are presented and then used to calculate various observables relevant to current experiments in the ultra-cold BEC-BCS crossover regime.

This project was supported by NSF funding.

D1.00005 2-Dimensional Compressed Magneto-Optical Trap

RAHUL MHASKAR, FOCUS Center, Physics Department, University of Michigan, VARUN VAIDYA, GEORG RAITHEL — We present an experimental implementation of a two-dimensional equivalent of a Compressed Magneto-Optical Trap (C-MOT [1]). A Zeeman slower produces a beam of rubidium atoms with flux $\sim 10^{11}$ atoms s$^{-1}$, velocity $\sim 25$ m/s, and propagation direction along the z-axis. The Zeeman-slowed atoms enter a magnetic field of the form $B \approx (az, -ay, 0)$ with a magnetic-field gradient $\alpha$ that increases with $z$. Four cooling laser beams intersect the atomic-beam axis in a manner that the value of $\alpha$ increases from about 10 G cm$^{-1}$ to about 50 G cm$^{-1}$ within the cooling region. As a result, a magneto-optic compression effect is achieved. The velocity of the extracted, compressed atomic beam can be varied via a frequency difference among the cooling beams. In contrast to pulsed C-MOTs (see Ref. [1]), our device operates continuously, and can be used as a starting point for the preparation of continuous-wave Bose Einstein Condensates and atom lasers. Simulations comparing the two-dimensional compressed MOT with a two-dimensional MOT without compression are presented. Future directions of the experiment will be discussed. [1] W. Petrich, M. H. Anderson, J. R. Ensher, E. A. Cornell, J. Opt. Soc. Am. 11, 1332 (1994).

D1.00006 Characterization of a Rubidium Magneto-Optical Trap

WEI WEN YU, BRAD CROCHET, GREGORY CARSON, ALINA GEARBA, Department of Physics and Astronomy, University of Southern Mississippi, Hattiesburg, MS 35406 — Recently at the University of Southern Mississippi, rubidium atoms were cooled and trapped in a standard magneto-optical trap (MOT). A systematic characterization of the rubidium MOT in terms of the number of trapped atoms versus several laser intensities, laser detunings, and magnetic field gradients is currently under way. The total amount of fluorescence emitted by the cold atoms is measured with a calibrated photodetector subtending a known solid angle, while a high-speed video camera connected to a computer via an image acquisition board is used to monitor the size and the shape of the atomic cloud. The first experimental results will be presented at the meeting.

D1.00007 Simultaneous Loading of $^87$Rb and $^85$Rb into a Optical Trap from a MOT

ANTHONY GORGES, DAVID FRENCH, JACOB ROBERTS, Colorado State University — We report on our experimental progress in simultaneously loading both $^87$Rb and $^85$Rb from a two-species Magneto-optic Trap (MOT) into a Far Off-Resonance Optical Trap formed by a single, focused CO$_2$ laser beam.

This work is supported by the AFOSR

2Now at the University of Michigan

D1.00008 External control of electron temperature in ultra-cold plasmas

DUNCAN TATE, ROY WILSON, MARGARET MARTEI, ANDERS WOOD, Colby College — In this presentation, we will discuss our progress towards achieving external control of the electron temperature and Coulomb coupling parameter of ultra-cold plasmas. The plasma is created by partial photoionization of a dense, cold sample of rubidium atoms in a MOT using a Littman dye laser (Rb density $\sim 4 \times 10^{11}$ cm$^{-3}$, temperature $\sim 100$µK). At a controllable time delay, neutral atoms embedded in the plasma are exposed to a specific Rydberg state by a narrow bandwidth pulsed laser. We measure the plasma electron energy spectrum as a function of delay between the lasers, as a function of the Rydberg state populated by the second laser, and as a function of Rydberg atom density. We have made progress towards quantifying and maximizing the Rydberg atom density that can be achieved by using mm-wave spectroscopy to control the evolution of a cold, dense Rydberg sample to plasma. We have also begun preliminary investigation of plasma electron temperature measurements. We are also investigating the use of a dark SPOT to increase the Rydberg density.

Research supported by Colby College and NSF.

D1.00009 Coherent Population Trapping in Quantum Gas of Fermions

ANDREW ROBERTSON, Department of Physics and Astronomy, Rowan University, Glassboro, New Jersey 08028-1700, LEI JIANG, HAN PU, Department of Physics and Astronomy, and Rice Quantum Institute, Rice University, Houston, TX 77251-1892, WEIPING ZHANG, Department of Physics, East China Normal University, Shanghai 200062, P. R. China., HONG LING, Department of Physics and Astronomy, Rowan University, Glassboro, New Jersey 08028-1700 — Coherent population trapping (CPT) is an important concept and a well known phenomenon in quantum optics. We generalize this concept from systems in quantum optics to systems in ultracold atomic physics. We consider a specific system, which is derived by introducing, in the usual BEC-BCS crossover model involving Feshbach resonance, an optical coupling between the ground and excited molecular states. We present the conditions under which a CPT superposition between the ground molecular BEC and the BCS pairing state can be formed. We take advantage the tunability offered by both magnetic and optical fields, and explore this superposition for the purpose of converting the BCS pairs into ground molecular BECs as well as demonstrating coherent oscillations between ground molecules and BCS atom pairs.

Acknowledgement: U. S. National Science Foundation, U. S. Army Research Office, National Natural Science Foundation of China, and Science and Technology Commission of Shanghai Municipality
D1.00010 Progress Towards a Quantum Gas Microscope

D1.00011 Ac-Stark shift of the hyperfine levels of alkali-metal atoms

D1.00012 Atomic coherence engineering using controllable phase-shifts: Towards a pulsed EIT-Raman lattice clock at JILA

D1.00013 Time-dependent quantum many-body theory of identical bosons in a double well

D1.00014 Measurement of the temperature dependence of the Casimir-Polder force

D1.00015 Heating of a BEC by mechanical perturbation

D1.00016 BEC apparatus for optical lattice experiments

D1.00017 ABSTRACT WITHDRAWN

D1.00018 A phase-space analysis of photoassociation of quantum degenerate molecules
D1.00119 Studies of Ultracold Collisions in $^{86}$Sr and $^{88}$Sr. P.G. MICKELSON, Y.N. MARTINEZ, S.B. NAGEL, T.C. KILLIAN, Rice University — We survey recent experiments with ultracold strontium performed in our group. Trapping and cooling occurs in three stages: successive magneto-optical traps (MOTs) operating on the 461 nm and 689 nm transitions of strontium, respectively, are loaded to cool atoms to a temperature of 1 µK. Finally, atoms are loaded into a far-off-resonance optical dipole trap. Photoassociation spectroscopy near the 461 nm line is performed directly in the 689 nm MOT, while other photoassociation experiments make use of the optical dipole trap. Various experiments reveal interesting physics of ultracold collisions in strontium.

D1.0020 Ultracold collisions between atoms and molecules in high vibrational states: effect of the atom-atom scattering length. GOULEN QUÉMÉNER, Department Of Chemistry, University of Nevada Las Vegas, Las Vegas, NV 89154, PASCAL HONVAULT, Laboratoire de Physique Moléculaire, Université de Franche-Comté, Besançon, France, JEAN-MICHEL LAUNAY, Laboratoire PALMS, Université de Rennes 1, Rennes, France — Recently, Bose-Einstein condensates of $^4$Li$_2$ and $^{40}$K$_2$ molecules have been produced using Feshbach resonances and Pauli blocking mechanism. In these experiments, molecules are formed in the highest vibrational state and composed by fermionic atoms, and the atom-atom scattering length is large and positive. Up to now, a few quantum-mechanical studies of molecular collisions in the ultralow energy range have been published [1]. Using a quantum-mechanical formalism based on hyperspherical coordinates, we have obtained elastic and inelastic rates coefficients for the fermionic system $^4$Li$_2$ and for the bosonic systems $^4$Li$_2^+$ and Na + Na$_2$ when the molecule is in a high vibrational state. We will also explain the Pauli blocking mechanism that occurs in the experiment, by comparing rates coefficients for a system composed of bosonic or fermionic atoms when the diatom is in the last vibrational state or not and when the atom-atom scattering length is increasing. [1] G. Quéméner, P. Honvault, J.-M. Launay, P. Soldà, D. E. Potter, J. M. Hutson, Phys. Rev. A 71, 032722 (2005), and references therein

D1.0021 Ultracold atom-molecule and molecule-molecule collisions. GOULEN QUÉMÉNER, T.J. DHILIP KUMAR, BALKRISHNADAN NADUVALATH, Department of Chemistry, University of Nevada Las Vegas, Las Vegas, NV 89154, TECK-GHEE LEE, Physics Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831, ROMAN KREMS, Department of Chemistry, University of British Columbia, Vancouver, Canada — Recent success in trapping and trapping of molecules has attracted much attention on cold and ultracold molecular collisions as well as controlled chemistry. Here we report on our progress on atom-molecule and molecule-molecule collisions in the ultracold region. The F+HCl/DCI systems are investigated to study the effect of long-range interactions in tunneling-molecule in chemical reactivity. The H$_2$-H$_2$ system is used as a prototype for the study of rotational and vibrational transitions in molecule-molecule collisions at ultracold temperatures. We will present results of reactive and nonreactive scattering on these systems including the relaxation of vibrationally excited H$_2$ molecules.

This work is supported by NSF grant No. PHY-0555565

D1.0022 Stark mixing under full interaction in ion-Rydberg atom cold collisions. RAYMOND FLANNERY, GOUTHAM BALARAMAN, Georgia Institute of Technology — A molecular dynamics simulation technique was developed to determine Stark mixing transitions, $n\ell \rightarrow n'\ell'$, in Rydberg atoms. The full ion-Rydberg atom interaction could therefore be employed. The transition probabilities were compared with the previous exact analytical results which are appropriate only to the ion-dipole interaction. The effect of higher-order multipoles could therefore be assessed. It is shown that the full interaction becomes important at extremely low incident speeds $\nu$ and small-intermediate impact parameters $b$. This importance is illustrated via various contour plots in the $b, \nu$-plane.

3Research supported by AFOSR and NSF

D1.0023 Cold and ultracold dipole-dipole collisions. CATHERINE NEWELL, MICHAEL CAVAGNERO, VLADIMIR ROUDNEV, University of Kentucky, JOHN BOHN, JILA and University of Colorado — Elastic collisions of ideal oriented dipoles are calculated using a variety of techniques appropriate to different cold and ultracold regimes of temperature. The elastic scattering cross section for two electric dipoles with moment $\mu$ in an electric field $E$ is obtained in the semi-classical Eikonal approximation, giving an exact result, $(4\pi\mu^2/e^2)[1 - (k_i^2 - E^2)^{1/2}]$, where $k_i = \mu E$ is the incident relative momentum. This result is expected to apply to collisions at temperatures above a few $\mu K$, encompassing recent experiments in the trapping and cooling of polar molecular gases. The Eikonal calculation contrasts sharply with the Born approximation which predicts an energy-independent cross section scaling as $1/\nu^2$. The scattering cross section for two electric dipoles with moment $\mu$ in an electric field $E$ is obtained in the semi-classical Eikonal approximation, giving an exact result, $(4\pi\mu^2/e^2)[1 - (k_i^2 - E^2)^{1/2}]$, where $k_i = \mu E$ is the incident relative momentum. This result is expected to apply to collisions at temperatures above a few $\mu K$, encompassing recent experiments in the trapping and cooling of polar molecular gases. The Eikonal calculation contrasts sharply with the Born approximation which predicts an energy-independent cross section scaling as $1/\nu^2$ and which should be applicable at lower temperatures. A separate analysis of the threshold ultracold region is also presented. Numerical close-coupling results connect these various approximation methods, and demonstrate that the crossover between semi-classical and perturbative regimes occurs at the characteristic dipole energy scale, $E_0 = \mu^2/e^2\nu^2$.

3Research supported by AFOSR and NSF

D1.0024 Measurements of Electron Temperature and Density, in an AC Pulsed Oxygen Plasma Discharge. FAROOK YOUSIF, Facultad de Ciencias, Universidad Autónoma del Estado de Morelos (UAEM), HORACIO MARTINEZ, Instituto de Ciencias Fisicas Univerdad Nacional Autonoma de Mexico, FERMIN CASTILLO, Instituto de Ciencias Nucleares Univerdidad Nacional Autonoma de Mexico — Emission and analytical spectroscopy was applied to investigate O$_2$ plasma, which was generated by an AC discharge between 0.15 and 0.5 Torr pressure. For the diagnostic study, a double Langmuir probe was employed. The derivation of plasma parameters is based on a theoretical description of the whole phase diagram of CeCoIn$_5$ including the change of the second order superconducting phase transition to the first-order one under the application of magnetic field. We present electron temperature and ion density as a function of the pressure at 3 different power discharge levels. Also we present emission spectroscopy in the wavelength range of 200-1100 nm as a function of the pressure.

1This work is supported by NSF grant No. PHY-0555565

D1.0025 Landau Paradigm and Universal Properties of Heavy-Fermion Metals. MIRON AMUSIA, Racah Institute of Physics, the Hebrew University, Jerusalem 91904, Israel, ALFRED MSEZANE, CTSPS, Clark Atlanta University, Atlanta, Georgia 30314, USA — Success in cooling and trapping of molecules was applied to investigate O$_2$ plasma, which was generated by an AC discharge between 0.15 and 0.5 Torr pressure. For the diagnostic study, a double Langmuir probe was employed. The derivation of plasma parameters is based on a theoretical description of the whole phase diagram of CeCoIn$_5$ including the change of the second order superconducting phase transition to the first-order one under the application of magnetic field. We present electron temperature and ion density as a function of the pressure at 3 different power discharge levels. Also we present emission spectroscopy in the wavelength range of 200-1100 nm as a function of the pressure.

1This work is supported by NSF grant No. PHY-0555565

2The main point of our theory is that quasiparticles form fermion-condensate state, achieved by a fermion condensation quantum phase transition (FCQPT). When the system of quasiparticles undergoes FCQPT, the fluctuations accompanying its quantum critical point are strongly suppressed and cannot destroy the quasiparticles. We present for the first time theoretical description of the whole phase diagram of CeCoIn$_5$ including the change of the second order superconducting phase transition to the first-order one under the application of magnetic field. We analyze dynamic conduction recently obtained in measurements on CeCoIn$_5$ and show that the particle-hole symmetry is violated in this metal making both the differential tunneling conductivity and dynamic conduction an asymmetric function of applied voltage. Our description of CeCoIn$_5$ based on the Landau paradigm and FCQPT is in good agreement with facts.
D1.00026 Superfluidity in a three component Fermi gas in a harmonic trap, TOMI PAANANEN, JANI-PETRI MARTIKAINEN, Division of Theoretical Physics, P.O.B 64, FIN-40014 University of Helsinki, Finland, PAIVI TORMA, Nanoscience Center, P.O.B 35, FIN-40014 University of Jyväskylä, Finland — Superfluidity in a two component Fermi gas has been recently achieved experimentally. However, a three component Fermi gas is also experimentally realistic in the very near future and has, until now, achieved only scant attention. We study ultracold three component Fermi gas in a harmonic trap. Components are different fermionic alkali atoms and they interact through s-wave interactions. There can be several different superfluid phases in the trap. These phases correspond to different pairing channels in the three component system. We show that these different phases can co-exist in a trap. Furthermore, by calculating the Gorkov correction caused by the induced interactions, we show that the many-body corrections to the mean-field theory are more pronounced for unequal mass fermion mixtures.

D1.00027 MONATOMIC, DIATOMIC, & MOLECULAR STRUCTURE —

D1.00028 Signature of Quantum Interference in Photorecombination of Ar-Like Ions, D. NIKOLIĆ, T.W. GORCZYCA, Western Michigan University, D.W. SAVIN, Columbia Astrophysics Laboratory, N.R. BADNELL, University of Strathclyde — We analyze both experimental (Schippers et al., J. Phys. B 31, 4873 (1998); Phys. Rev. A 66, 042723 (2002)) and calculated total cross sections for dielectronic recombination (DR) of Ar-like Sc$^{3+}$ and Ti$^{4+}$ ions in the vicinity of the $3p^53d^2$ and $3p^53d4s$ doubly-excited, highly-correlated resonances. Our R-matrix approach provides a unified quantum-mechanical description of the electron-ion photorecombination (PR) process, treating radiative recombination and DR as coherently interfering pathways for the rare asymmetric profiles of the strong $3p^53d^2 \, 2F_7/2,5/2$ near-threshold resonances. In order to treat the PR completely and more practically, all additional (Lorentzian) resonance contributions for the rest of the Rydberg series are calculated within an independent-processes, isolated-resonance, distorted-wave approximation using the atomic structure and collision code AUTOSTRUCTURE.

D1.00029 Dielectronic Recombination of Al-Like Sulfur, SH. A. ABDEL-NABY, D. NIKOLIĆ, T.W. GORCZYCA, Western Michigan University, N.R. BADNELL, University of Strathclyde, D.W. SAVIN, Columbia Astrophysics Laboratory — Accurate dielectronic recombination (DR) data are important for cosmic and laboratory plasma modeling. Over the past few years, our group has computed reliable DR data for all isoelectronic sequences up through Mg-like ions. Recently, we have focused our work on the complex third-row M-shell isoelectronic sequences. Al-like Fe$^{13+}$ DR calculations have been completed and tested against Heidelberg heavy-ion Test Storage Ring facility measurements. We extend our efforts for Al-like systems to S$^{3+}$. Although previous calculations on S$^{3+}$ exist, they were performed only within a non-relativistic LS-coupling approximation. Here we present DR rate coefficients for Al-like S$^{3+}$ using the level-resolved, multi-configurational, distorted-wave AUTOSTRUCTURE package. In order to describe the S$^{3+}$ target accurately, we extended the basis configurations previously used in Al-like Fe$^{13+}$. New results will be presented, and comparisons against available data will be shown.

D1.00030 K-shell Fluorescence Yields of Li- to F-like Ions, S.T. MANSON, Department of Physics and Astronomy, Georgia State University, Atlanta, GA 30303, M.F. HASOGLU, T.W. GORCZYCA, Department of Physics, Western Michigan University, Kalamazoo, MI 49008-5252, N.R. BADNELL, Department of Physics, University of Strathclyde, Glasgow, G4 0NG, UK, D.W. SAVIN, Columbia Astrophysics Laboratory, Columbia University, New York, NY 10027 — We have investigated the accuracy of the commonly-used fluorescence/Auger database. These data were determined from configuration average, LS, singly-charged atomic physics calculations and were then scaled up through Z=30 for all isoelectronic sequences through the iron peak elements. We have carried out new calculations, using the AUTOSTRUCTURE package, and demonstrate the significance of including properly such physical effects as correct configuration averaging (CA), semi-relativistic (i.e., spin-orbit) effects, and the previously-overlooked need to tailor the CA itself to the specific physical process of interest, showing that the extant database includes significant inaccuracies. Finally, we have completed an investigation of the isoelectronic sequences of all second-row ions. This work was supported in part by NASA-APRA and SHP SR&T, and UK PPARC grants.

D1.00031 Study of dynamics of Rabi oscillation under a pulsed perturbation using hyperfine transition of trapped cesium atoms, JAI MIN Choi, GEE-NA KIM, D. CHO, Department of Physics, Korea University — We study dynamics of Rabi oscillation under a periodic pulsed perturbation. We study how the resonance frequency of a cesium ground hyperfine transition between sublevels with nonzero magnetic quantum number is affected by periodically applied magnetic pulses. When the pulse height and pulse duration are set such that a fictitious spin completes a $2\pi$ or its integer multiple precession across the principal quantization axis, there is no frequency shift [1]. We carry out the experiment using spin-polarized cesium atoms trapped in a magneto-optical trap. This has an important implication for metrological application of atoms trapped in an optical trap, where a systematic frequency shift and inhomogeneous broadening due to an ac Stark shift limits accuracy and precision. Our method is complimentary to the ones using a magic wavelength in a multi-level configuration [2-4] or a polarization dependence of the ac Stark shift to compensate for the differential ac Stark shift [5].


D1.00032 Third-order relativistic many-body calculation of matrix elements for divalent systems, DANSHA JIANG, RUPSI PAL, MARIANNA SAFRONOVA, University of Delaware — Third-order relativistic many-body perturbation theory (MBPT) formulas for the calculation of the transition matrix elements in systems with two valence electrons are derived. The two-particle contributions are identified among 162 third-order Goldstone diagrams and organized into 17 terms. The one-particle contributions are identical to the previously studied third-order terms in monovalent systems. Complete angular reductions of the third-order amplitudes are given. The model potential is taken to be the Dirac-Hartree–Fock (DHF) potential $V^{(N-2)}$ of the closed core. We use B-splines to generate a complete set of DHF basis orbitals for the numerical evaluation of the perturbation theory terms. The effect of the Breit interaction is also investigated. The preliminary results of the third-order calculations are presented for selected systems. Comparisons are made with second-order MBPT results, and with other calculations.
D1.00033 A DFT approach for the accurate calculation of triply excited hollow and doubly-hollow Rydberg resonances in lithium isoelectronic sequence, AMLAN KUSUM ROY, Department of Chemistry and Biochemistry, University of California, Los Angeles, CA, 90095, USA — Density functional calculations are performed for the \( 22^2\ell n^l \) \((n \geq 2)\) triply excited \textit{hollow} resonances in lithium isoelectronic sequence. An amalgamation of the local nonvariational work-function-based exchange potential and LYP correlation functional is used. Radial KS equation is solved accurately through the Generalized pseudospectral method, leading to a nonuniform and optimal spatial discretization. Results are presented on the excited-state energy, excitation energy, radial density and other expectation values. A large number of states are studied, covering low, moderately-high and high-lying excitations, with \( n \) as high as up to 25, having varied symmetries and multiplicities. Companion calculations are made for the \( 33^3\ell n^l \) \((n \geq 3)\) \textit{double-hollow} states of Li in the photon energy range of 176-181 eV. Detailed comparisons with recent theoretical and experimental results show excellent agreement. Many new resonances are presented for the first time, which can provide useful guidelines for future studies. This provides a simple, efficient and general scheme for reliable and accurate treatment of multiply excited Rydberg resonances in atoms within DFT.

D1.00034 B-splines in variational atomic structure theory, CHARLOTTE FROESE FISCHER, National Institute of Standards and Technology — Many of the problems associated with the use of finite differences for the solution of variational Hartree-Fock or Dirac-Hartree-Fock equations are related to the orthogonality requirement and the need for node counting to control the computed solution of a two-point boundary value problem with many solutions. By expanding radial functions in a B-spline basis, the differential equations can be replaced by non-linear systems of equations of eigenvalue type. Hartree-Fock orbitals become solutions of generalized eigenvalue problems where orthogonality requirements can be dealt with through projection operators applied to the matrix that preserve the symmetry of the matrix. When expressed as banded systems of equations, all orbitals may be improved simultaneously using singular value decomposition or the Newton-Raphson method for faster convergence. Computational procedures will be outlined for non-relativistic multiconfiguration Hartree-Fock variational methods and extensions to the calculation of Rydberg series. It will also be shown how tensor products of B-splines can be applied to the calculation of two-electron pair-correlation functions where high-order partial waves improve the short-range electron-electron cusp condition at \( r_1 = r_2 \).

D1.00035 Atomic Spectra Bibliography Databases at NIST, A.E. KRAMIDA, National Institute of Standards and Technology — In June 2006, our Atomic Spectroscopy Data Center released three new Bibliographic Databases (BD) containing references to papers with atomic data for controlled fusion research, modeling and diagnostics of astrophysical and terrestrial plasmas, and fundamental properties of electronic spectra of atoms and ions. The NIST Atomic Energy Levels and Spectra BD (http://physics.nist.gov/elevidbd) [EL] is the first online version of the NIST bibliography on atomic energy levels and spectra, last published on paper in 1985. It includes more than 9300 references, mostly for years 1967 through 2004. Work is in progress to cover the latest years. The NIST Atomic Transition Probability BD, v. 8.1 (http://physics.nist.gov/ftablebd) [TP] with its 7200 references mainly covers years 1986 through 2006. The NIST Spectral Line Broadening BD, v. 2.0 (http://physics.nist.gov/linebndbd) [LB] has 3600 references, mostly for 1978 through 2006. It is a major upgrade of v. 1.0, which had only 800 references. All three databases are now maintained in a unified database management system that allows us to quickly update the contents. Updates become available to users on the next day. A new Data Entry module makes it easy to enter and categorize the data. This work is supported in part by the Office of Fusion Energy Sciences of the U.S. Department of Energy.

D1.00036 Balmer Line Broadening in Laser Produced Hydrogen Plasma, LUTZ HUWEL, ROLAND VOLKL, YUDHISHTHIR KANDEL, Wesleyan University — Photoionized plasmas have been created in hydrogen by focusing a 10 ns, 20 Hz, 1064 nm Nd:YAG laser pulse into gas at a pressure of 10^5 Pa. The focal zone power density is about 10^11 W/cm^2. The afterglow of these plasmas has been studied with gated contributions to the Dirac-Fock potential and then treat the residual Breit and Coulomb interactions perturbatively. Results obtained from the two versions are compared and discussed. Theoretical excitation energies are compared with critically evaluated experimental data and with results from other recent calculations. Trends of excitation energies including splittings of triplet terms as functions of nuclear charge \( Z = 34-100 \) are illustrated graphically for some states. The resulting \( Z \)-dependence shows explicitly the effect of mixing \( |4p^d + 4s 4d\ell \rangle, |4d^2 + 4p 4d\ell \rangle, \) and \( |4p 4d + 4s 4f\ell \rangle \) configurations.

D1.00037 Relativistic many-body calculations of the energies of \( n=4 \) states for zircon-like ions, WALTER JOHNSON, University of Notre Dame, STEVEN BLUNDELL, DFRMC/SPSMS CEA-Grenoble, ULYANA SAFRONOVA, University of Nevada, Reno — Energies of the 44 even-parity and 40 odd-parity (44\ell) states of ions of the zircon isoelectronic sequence are evaluated through second order in relativistic many-body perturbation theory. Our results start from a Ni-like \( \ell(N-2) \) Dirac-Fock potential. Two alternative treatments of the Breit interaction are investigated. In the first version, we omit Breit contributions to the Dirac-Fock potential and evaluate Coulomb and Breit-Coulomb corrections through second order perturbatively. This version was used previously to evaluate energies Be- through Yb-like systems. In the second version, we include both Coulomb and Breit contributions to the Dirac-Fock potential and then treat the residual Breit and Coulomb interactions perturbatively. Results obtained from the two versions are compared and discussed. Theoretical excitation energies are compared with critically evaluated experimental data and with results from other recent calculations. Trends of excitation energies including splittings of triplet terms as functions of nuclear charge \( Z = 34-100 \) are illustrated graphically for some states. The resulting \( Z \)-dependence shows explicitly the effect of mixing \( |4p^2 + 4s 4d\ell \rangle, |4d^2 + 4p 4d\ell \rangle, \) and \( |4p 4d + 4s 4f\ell \rangle \) configurations.

D1.00038 Excitation energies, polarizabilities, multipole transition rates, and lifetimes for francium-like ions, WALTER JOHNSON, Notre Dame University, STEVEN BLUNDELL, DFRMC/SPSMS CEA-Grenoble, ULYANA SAFRONOVA, University of Nevada, Reno, MARIANNA SAFRONOVA, University of Delaware — Energies of 7s, 7p, 6d, and 5f states in Fr-like ions with nuclear charges \( Z = 87 - 100 \) are evaluated using relativistic many-body perturbation theory complete through third order. Reduced matrix elements, oscillator strengths, and transition rates are evaluated for the 7s-7p, 7p-6d, and 6d-5f electric-dipole transitions. Multipole matrix elements for 7s-6d, 7s-5f, and 5f-5f transitions are evaluated to determine lifetimes of low-lying excited states. Energies, lifetimes, and transition matrix elements for ions \( Z = 87 - 92 \) are also evaluated using the relativistic single-double (SD) method, where single and double excitations of Dirac-Fock wave functions are iterated to all orders in perturbation theory. Ground state scalar polarizabilities in Fr, Ra, Ia, Ac III, and Th IV are evaluated using both third-order and all-order methods.

1 Supported in part by NSF Grants No. PHYS-04-05682 and PHYS-04-045078

D1.00039 Isotope Shifts and Fine Structures of \( ^{6,7}\)Li D Lines and Determination of Relative Nuclear Charge Radius, GEORGE NOBLE, WILLIAM VAN WINGAARDEN, York University — The \( ^{6,7}\)Li D lines were excited using an electro-optically modulated CW dye laser that intersected an atomic beam. Fluorescence was recorded as the laser was scanned across the resonance. Hence, each transition was excited multiple times allowing for calibration of the frequency scan. The \( ^{6}\)Li \( 2p \) fine structures were found to be 10052.964 \( \pm 0.050 \) and 10053.119 \( \pm 0.058 \) MHz. The D1 and D2 isotope shifts were determined to be 10534.039 \( \pm 0.070 \) and 10534.194 \( \pm 0.104 \) MHz. The latter imply values for the \( ^{6,7}\)Li relative nuclear charge radius that are within 20 milliunits of each other which is consistent with the estimated uncertainties.

2 Financial support from the Natural Sciences and Engineering Research Council of Canada (NSERC) is greatly appreciated.
D1.00040 Anisotropy Dependent Circular Polarization Spectra in Cs $6p^2P_{3/2}$ level$^1$, BURCIN BAYRAM, RAMESH MARHATTA, JACOB HINKLE, PRAKASH KOIRALA, Physics Department, Miami University, Oxford, Ohio 45056 — Experimental investigation of the cesium $6s^2S_{1/2} \rightarrow 10s^2S_{1/2}$ two-photon circular polarization spectra has been made. The time evolution of anisotropies, namely orientation and alignment state multipole, in the excited state and their effects to the circular polarization spectra have been shown. Collisions between the excited level cesium atoms and the ground level argon atoms in the gas phase yielded anisotropy dependent depolarization cross section to be extracted from the measured circular polarization degree. Experimental details and the results will be presented.

$^1$Supported by the Research Corporation CC6119.

D1.00041 A grid-based DFT method for the electronic structure calculation of many-electron systems, AMLAN K. ROY, SHIH-I. CHU, Department of Chemistry, University of Kansas, Lawrence, KS, 66045, USA — We propose a new simple pseudopotential density functional method along with its implementation for the efficient and accurate treatment of electronic properties of molecules. The atom-centered localized gaussian basis sets, the electronic density as well as the various potentials are directly set up in a real uniform grid of three-dimensional cubic box. The nonrelativistic Kohn-Sham equation is solved within a linear combination of atomic orbitals-molecular orbitals (LCAO-MO) framework on grid using the standard self-consistent procedure. As a first step, simple local XC functionals and Hay-Wadt-type pseudopotentials are employed. As an illustration, we compare the total energy, eigenvalue, potential energy curve, the equilibrium bond length and vibrational frequency for CI and HCl molecule, which show very good agreement with the reference data. This provides a simple practical route to accurate molecular quantum mechanical calculations.

D1.00042 Theoretical Fit to Experimental Observations of Energy Level Structure in the Cs$_2$ $\alpha^3\Sigma^+_u$ State$^1$, T. BERGEMAN, SUNY Stony Brook, S. SAINIS, Yale, E. TIESINGA, NIST, D. DEMILLE, Yale — Precision measurements$^2$ on 27 hyperfine/rotational levels from 6 vibrational levels of the Cs$_2$ $\alpha^3\Sigma^+_u$ state, with binding energies as large as 50 cm$^{-1}$, have been performed. The objective is to identify suitable transitions to probe the energy difference between a level of a shallow bound state ($\alpha$) and a level of a more deeply bound state ($\chi^1\Sigma^+_u$) to be used ultimately to study the time variation of the electron to proton mass ratio$^2$. It is therefore important to characterize the singlet-triplet ($X - \alpha$) mixing due to hyperfine interactions. We have modeled the energy level structure by using a Hund’s case $e$ asymptotic representation for the hyperfine interaction and rotational energy, and a case $a$ representation for the Born-Oppenheimer potentials and second-order spin-orbit (SO) interactions, with transformations between the two representations. Potentials and SO effects are adjusted to optimally fit the data. Currently, the rms residual from the fit is about twice the 30 MHz uncertainty for energy differences within each vibrational level.

2. D. DeMille et al., to be published.

$^1$Supported by NSF, ONR, and ARO

D1.00043 Newly observed rovibrational levels of the 3 and 4$^1\Sigma^+_u$ states in molecular hydrogen$^1$, AARON MARKS, JOE CROMAN, Bryn Mawr College, ROBERT EKEY JR., University of Mary Washington, ELIZABETH MCCORMACK, Bryn Mawr College — Double resonance spectroscopy via the EF$^1\Sigma^+_u, v_{EF} = 6, J'$ state has been used to probe the rovibrational structure of the ungerade double-well $B^+B(3)^1\Sigma^+_u$ state of H$_2$. Many transitions have been observed for the first time by detecting both molecular and atomic ion production as a function of energy by using a time-of-flight mass spectrometer. Rovibrational states with $J = 0-4$ and $v = 50$ up to the $n = 3$ dissociation limit are reported. A comparison of the experimentally determined and theoretically calculated rotational constants using the latest set of ab initio molecular potentials is presented. In addition, transitions to the $4^1\Sigma^+_u, J = 10$, state, the next electronic state in the series, have been observed for the first time and term energies are reported. The double-well $^1\Sigma^+_u$ states are of interest because they have unusually large internuclear separation, and while many levels lie above the ionization potential, they remain extremely stable against autoionization. The new energy measurements presented here provide significant constraints on ab initio calculations of the $^1\Sigma^+_u$ series in this fundamental system.

$^1$This work supported by a grant from the NSF (PHY-0140296).

D1.00044 A continuous molecular beam source of lead monofluoride, P. SIVAKUMAR, C.P. MCRAVEN, N.E. SHAFER-RAY, University of Oklahoma — Due to its insensitivity to background magnetic fields combined with large internal electric fields, the ground-state of lead monofluoride (PbF) may be uniquely sensitive to an electron electric dipole moment (PRA, 73, 034102, 2006). The serendipitous discovery of MgF$_2$ and SHAFER-RAY, University of Oklahoma — Due to its insensitivity to background magnetic fields combined with large internal electric fields, the ground-state of lead monofluoride (PbF) may be uniquely sensitive to an electron electric dipole moment (PRA, 73, 034102, 2006). The serendipitous discovery of MgF$_2$ and PbF yielding PbF has enabled us to build a reliable continuous molecular beam source of lead monofluoride. Details of the source and detection of the molecule are presented.

D1.00045 ABSTRACT HAS BEEN MOVED TO C6.00013 —

D1.00046 First results from the CLS far-infrared beamline: the $\nu_{12}$ and $\nu_{17}$ bands of acrolein, CH$_2$CHCHO$^1$. DENNIS TOKARYK, University of New Brunswick, Physics Department, A. ROBERT MCKELLAR, National Research Council of Canada, LI-HONG XU, University of New Brunswick, Saint John, Department of Physical Sciences, DOMINIQUE APPADOO, TIM MAY, Canadian Light Source, University of Saskatchewan — Synchrotron radiation from the new Canadian Light Source facility has been used to obtain a high resolution (0.0012 cm$^{-1}$) absorption spectrum of acrolein vapor in the 550-660 cm$^{-1}$ region. Almost 2000 transitions have been included in a detailed analysis of the $\nu_{12}$ (~564 cm$^{-1}$) and $\nu_{17}$ (~593 cm$^{-1}$) fundamental bands, yielding precise values for the band origins, rotational and centrifugal distortion parameters. The analysis included the a- and b-type Coriolis interactions connecting $\nu_{12}$ and $\nu_{17}$, as well as an a-type Coriolis interaction between $\nu_{17}$ and a “dark” perturbing state, identified as $4\nu_{18}$. We believe that this is the first high-resolution infrared study of acrolein.

$^1$Support from the Natural Sciences and Engineering Research Council of Canada (NSERC) is gratefully acknowledged by D. Tokaryk and L.-H. Xu.
D1.00047 Geometric Phase in rotating Electric and Magnetic Fields\footnote{This work supported by the NSF}.

EDMUND MEYER, RUSSELL STUTZ, LAURA SINCLAIR, AARON LEANHARDT, ERIC CORNELL, JOHN BOHN, JILA — Berry’s original formulation of the geometric phase \cite{1} considered adiabatic transport of a structure-less spin by a magnetic field around a closed circuit, and found an additional phase of geometric origin. We have generalized Berry’s notion to structured atoms and molecules, where different constituents contribute differently to the net magnetic and electric dipole moments. In particular, we present numerical simulations describing the geometric phase gained by a paramagnetic, polar molecule in simultaneous magnetic and electric fields. Of particular interest is the behavior of the geometric phase as the fields span the intermediate range between “low” and “high”, as compared to the hyperfine structure of the molecule. [1] M. V. Berry, F.R.S., Proc. R. Soc. Lond. A., 382, 45 (1984).

D1.00048 Dissociative Fragmentation of Polyyclic Aromatic Hydrocarbons with 532 nm Laser Radiation.

CARMEN CISNEROS, Universidad Nacional Autonoma de Mexico, JUAN CARLOS POVEDA, Universidad Nacional Autonoma de Mexico, MANUEL COMBES, ALFONSO GUERRERO, IGNACIO ALVAREZ, Universidad Nacional Autonoma de Mexico — A pulsed supersonic jet of polyaromatic hydrocarbons mixed with noble gases was produced by adiabatic expansion in a high vacuum chamber (2x10\footnote{W}\textsuperscript{−}8 torr). The PAH’s were heated in order to obtain their vapors. The pulsed mixtures interacted at 90˚ degrees with the 532 nm laser radiation from second harmonic of a Nd:YAG laser at intensities of 10\footnote{10}\textsuperscript{11}-10\footnote{12} W\textsuperscript{−}cm\textsuperscript{2}. The produced ions from photodissociation-photoionization processes were extracted, accelerated at 3.5 keV and analyzed in a time of flight mass spectrometer. In previous work \cite{1} with 355 nm, only low mass ions were detected. At the present wave length, single charged ions were observed with compositional arrangements of the type C\footnote{11}H\footnote{12} where 3\footnote{<} n \footnote{<} 9 and m in the range of 1 to n, with some exceptions when protonation occurs. Double charged ions were observed and they are more abundant than in the case of the 355 nm photodissociation. The carrier gas effect was also analyzed and differences in the ion currents were present as a consequence of the solvatation effectiveness of the van der Waals interaction. (1) Poveda J.C., Guerrero A., Alvarez I., Cisneros C. 17 Th Int. Mass Spectr. Conference. MoP – 062 Prague Aug. 27 – Sept. 1 2006

D1.00049 PHOTON INTERACTIONS WITH ATOMS, IONS, AND MOLECULES; SHORT PULSE PROCESSES —

D1.00050 Theory of x-ray absorption by laser-dressed atoms\footnote{C.B. is self-employed (Germany) and was funded by a Feodor Lynen Research Fellowship from the Alexander von Humboldt Foundation. R.S.’s work was supported by the Office of Science, U.S. Department of Energy, under Contract No. DE-AC02-06CH11357}.

CHRISTIAN BUTH, ROBIN SANTRA, Argonne National Laboratory, Argonne, Illinois 60439, USA — We present an ab initio theory for the x-ray photoabsorption cross section of atoms in the field of a moderately intense optical laser (800 nm, 10\footnote{13} W\textsuperscript{−}cm\textsuperscript{2}). The laser dresses the core-excited atomic states, which introduces a dependence of the cross section on the angle between the polarization vectors of the two linearly polarized radiation sources. The strong interaction due to the laser-dressing is treated by diagonalization of a Floquet-type matrix; the weak coupling between x-rays and the atom is described by non-Hermitian perturbation theory. We apply our theory to study the photoabsorption cross section of neon and krypton atoms near the K edge. A pronounced modification of the cross section is found in the presence of the optical laser — reference: arXiv:physics/0611122.

D1.00051 Interpretation of black body radiation as a decay process.

CLARENCE A. GALL, Division de Postgrado de Ingenieria, Universidad del Zulia, Apartado # 98, Maracaibo, Zulia, Venezuela — The treatment of black body radiation as a decay process with the wavelength (\lambda) as the time marker, leads to an apportioning function (I_\lambda) that distributes the total thermodynamic Stefan-Boltzmann emitted intensity (I) over the entire wavelength range (Clarence A Gall, BAPS, March Meeting 2007, Denver, CO). The resulting distribution function \( I_\lambda = ID_\lambda = \sigma T^4 \lambda e^{\frac{\lambda}{kT}} \) gives the Stefan-Boltzmann law on integration over the same interval. Differentiation of \( I_\lambda \) produces Wien’s displacement law as the condition for the wavelength at maximum emitted intensity (\lambda_m). Substitution of \( \lambda_m \) in \( I_\lambda \) yields the maximum emitted intensity \( (I_{\lambda_m}) \) as being proportional to \( T^5 \). Hence \( I_\lambda \) satisfies exactly the three known empirical laws of black body radiation and fulfills Einstein’s hope for a solution of the radiation problem without the use of light quanta. Finally the replacement of \( \frac{1}{\lambda^4} \) with a single constant \( G \) simplifies the distribution function so that \( I_\lambda = \sigma_\lambda G^4 e^{\frac{\lambda}{kT}} \) where \( \sigma_\lambda = b^4 \sigma \). Consequently \( G \) defines a new temperature scale with units of reciprocal wavelength that unifies the thermodynamic and colour scales.

D1.00052 Partial and Complete Transfer of Energy in Bremsstrahlung Must Include Spin and Vibrational Kinetic Energies.

STEWART BREKKE\footnote{previous paper at March 07 meeting}.

Northeastern Illinois University — When complete braking is achieved, the spin and vibrational kinetic energies as well as linear kinetic energy is transferred to the resulting photon: \( h\nu = 1/2mv^2 + 1/2I_\omega^2 + (n+1/2)\hbar_\omega \). If partial transfer of kinetic energy is achieved by decelerating a charged particle, then the resulting photon is \( [1/2mv^2 + 1/2I_\omega^2 + (n+1/2)\hbar_\omega] - [1/2mv^2 + 1/2I_\omega^2 + (n+1)\hbar_\omega] \). 1/2I_\omega^2 is the spin kinetic energy and \((n+1/2)\hbar_\omega\) is the vibrational kinetic energy. By using the spin and vibrational factors some recombination of experimental and theoretical values can be achieved.

D1.00053 Compton Effect and Pair Production and Annihilation Formulas Should Include Spin and Vibrational Energy Factors.

STEWART BREKKE\footnote{previous papers presented on subject}.

Northeastern Illinois University — The correct formula for the Compton Effect should spin and vibrational energies before and after the photon collision: \((hf + mc^2 + 1/2I_\omega^2 + (n+1/2)\hbar_\omega) = hf + (pc^2) + (mc^2)^{21/2} + 1/2I_\omega^2 + (n+1/2)\hbar_\omega\). The pair annihilation formula should be \( 2hf = m_e c^2 + m_e c^2 + 1/2I_\omega^2 + (n+1/2)\hbar_\omega + 1/2I_\omega^2 + (n+1/2)\hbar_\omega\). In pair creation the photon energy must also go to the vibrational and spin kinetic energies besides linear kinetic energies of the created particles. By using the vibrational and spin kinetic energies some recombination between theoretical and experimental values may be achieved.
D1.00054  Systematic study of zeros in bound-free matrix elements, L.A. LAJOHN, R.H. PRATT, University of Pittsburgh, S.T. MANSON, Georgia State University — We extend the systematic study of the positions in photon energy at which radial matrix elements are zero, well known for dipole matrix elements, to quadrupole matrix elements, considering the full range of the periodic table. For nonrelativistic dipole matrix elements there are zeros (Cooper minima)(CM) only for screened (not pure point Coulomb) potentials, at energies of a few of tens of eV. There are relativistic zeros (RC) that are independent of potential at much higher energies, around 100 keV or higher. For the case of quadrupole matrix elements, CM and RC zeros are again found in certain channels, but there is also a third class of zeros in an intermediate energy regime (order of 10 keV), already present in the point Coulomb potential (NRC), but modified by screening. These quadrupole zeros have important consequences, particularly for photoelectron angular distributions. Zeros occur in sequences, of one type for CM and NRC, and of another for RC.

D1.00055  Searching for exotic particle emission in the decay of trapped Rb isomers, T. KONG, R. PITCAIRN, UBC, A. GORELOV, SFU, J. FUNG, C. HOHR, M. PEARSON, J. BEHR, TRIUMF, Vancouver, Canada — During the decay of nuclear isomers, the momentum of the recoil nucleus will change if any massive particle is emitted instead of a Gamma ray. The Rb isomer transitions are sensitive to a mass range between 20 to 550 keV/c². This range covers masses for pseudoscalar axions which were proposed to solve the “strong CP” problem and for scalar particles. In our experiment, trapped metastable Rb isomers will be used to search for these particles. To measure the recoiling momentum, the daughter Rb atoms are photo-ionized. The resulting electrons and photo-ions are detected in a MOTRIMS setup, where charged particles are guided onto time and position sensitive detectors by means of electric fields. The photo-ionization involves firstly the excitation from 5S state to 5D state by Doppler-free two-photon transition using an MBR-110 laser at 778nm, and then ionization to the continuum by a broadband diode laser bar.

D1.00056  Absorption measurements of alkali-metal resonance lines broadened by He and molecular hydrogen collisions, F. SHINDO, J. BABB, K. KIRBY, Harvard-Smithsonian CfA — The optical and near-infrared spectroscopic observations of cool brown dwarfs exhibit very prominent signatures of sodium and potassium resonance lines. The atmospheres of these objects are mainly composed of molecular hydrogen and helium and the collisions of this species with the alkali-metal atoms induce broadening of the K and Na resonance lines by as much as 100 nm either side of the line core. Particularly important are the far line wings, where satellite features which are usually very temperature-sensitive may appear due to extrema in the difference potentials. These features are highly sensitive to pressure and temperature, whereas their position and shape depend critically on the details in the interaction potentials. Accurate line profiles can serve as valuable diagnostics of the physical characteristics of brown dwarfs and extrasolar giant planets. Experimental determinations of the far wings are indispensable in validating the theoretical models. We report here our measurements of the absorption coefficients for pressure broadening in the far wings of the 4s-4p and 4s-5p doublet lines of potassium atoms in the presence of helium and hydrogen gas at temperatures around 900 K. Supported in part by NASA grant NNG06GF06G.

D1.00057  Determining accurate laser intensity dependence despite the intensity-volume effect with z-scanning intensity-difference spectra, A. MAX SAYLER, PENQIANG WANG, NORA G. JOHNSON, BISWANATH GAIRE, KEVIN D. CARNES, ITZIK BEN-ITZHAK, J.R. Macdonald Laboratory, Department of Physics, Kansas State University — A focal spot or z-scanning intensity-difference spectrum method is developed to allow the determination of the intensity dependence of laser-produced features while improving experimental statistics. This method is applicable to a focused Gaussian beam interacting with an approximately uniform planar target. We apply this method to the angularly resolved kinetic energy release spectra of laser-induced dissociation of O₂⁺ and H₂⁺ so as to keep the exact contribution from a predetermined intensity range and eliminate the contributions from outside this range.

D1.00058  Phase noise to intensity noise conversion in EIT, YANHONG XIAO, TUN WANG, MICHAEL HOHENSEE, IRINA NOVIKOVA, DAVID PHILLIPS, SUSANNE YELIN, RONALD WALSWORTH, Harvard-Smithsonian — Laser phase noise can induce intensity noise after interacting with an atomic medium. This process plays a critical role in determining the performance of systems employing electromagnetically induced transparency (EIT), including certain types of atomic clocks. We present an experimental and theoretical study of EIT noise spectra and correlations in a Rb vapor cell. Variations of noise features with laser frequency and two-photon detunings are studied systematically with particular emphasis on noise correlations between the two output fields.

D1.00059  Photoionization and electron-impact ionization of Ar⁵⁺, JING CHENG WANG, M. LU, D. ESTEVES, M. HABIBI, G. ALNA’WASHI, R.A. PHANEUF, University of Nevada, Reno, A.L.D. KILCOYNE, Advanced Light Source, LBNL, B.M. MCLAUGHLIN, UBC, A. GORELOV, SFU, J. FUNG, C. HOHR, M. PEARSON, J. BEHR, TRIUMF, Vancouver, Canada — During the decay of nuclear isomers, the momentum of the recoil nucleus will change if any massive particle is emitted instead of a Gamma ray. The Rb isomer transitions are sensitive to a mass range between 20 to 550 keV/c². This range covers masses for pseudoscalar axions which were proposed to solve the “strong CP” problem and for scalar particles. In our experiment, trapped metastable Rb isomers will be used to search for these particles. To measure the recoiling momentum, the daughter Rb atoms are photo-ionized. The resulting electrons and photo-ions are detected in a MOTRIMS setup, where charged particles are guided onto time and position sensitive detectors by means of electric fields. The photo-ionization involves firstly the excitation from 5S state to 5D state by Doppler-free two-photon transition using an MBR-110 laser at 778nm, and then ionization to the continuum by a broadband diode laser bar.

D1.00060  The Iron Project and the RMAX Project: Transitions in Fe XV, Fe XVI, and Astrophysical Applications, MAXIMILIANO MONTENEGRO, SULTANA NAHAR, ANIL PRADHAN, CHIRANJIB SUR, The Ohio State University, JUSTIN OELGOETZ, Los Alamos National Laboratory — While the Iron Project is involved in scattering and radiative atomic processes of iron and iron-peak elements, the Rmax Project aims at the X-ray spectroscopy of astrophysical objects. Under the Iron Project, the oscillator strengths and radiative decay rates for fine structure transitions going up to n=10 and l=9 are obtained for magnesium like Fe XV and sodium like Fe XVI. They correspond to 98 levels for Fe XVI and 504 levels for Fe XV. We have employed relativistic Breit-Pauli R-matrix method for the allowed electric dipole (E1) transitions and Breit-Pauli atomic structure calculations for forbidden (E2, E3, M1, M2) transitions for these ions. The results have been benchmarked against the ab initio coupled cluster method which includes relativistic effects. Very good agreement is found for Fe XVI. The application of the Iron Project and the RmaX Project data to laboratory and astrophysical sources is demonstrated for time-resolved spectroscopy of X-ray lines of He-like Fe and Ni, especially for the astrophysical diagnostic lines.

1 Partially supported by NASA Astrophysical Theory Program.
D1.00611 Ab Initio Theoretical Investigation of the Frequency Comb Structure in the XUV Regime via High Harmonic Generation\textsuperscript{1}. JUAN J. CARRERA, University of Kansas, SANG-KIL SON, University of Kansas, SHIH-I. CHU. University of Kansas — We present an ab initio quantum investigation of the frequency comb structure formed within each high harmonic generation (HHG) power spectrum driven by a train of equal- spacing short laser pulses. The HHG power spectrum of atomic hydrogen is calculated by solving the time-dependent Schrödinger equation accurately and efficiently by means of the time- dependent generalized pseudospectral method. We found that the frequency comb structure is preserved within each harmonic. In addition, the repetition frequency of the comb laser depends upon the pulse separation $\tau$ and the spectral width of each individual comb fringe is inversely proportional to the number of pulses ($n$) used. However, the overall HHG power spectrum pattern depends only upon the laser frequency and intensity used and is not sensitive to the $\tau$ and $n$ parameters. Finally, the frequency comb structure persists even in the presence of appreciable ionization.

\textsuperscript{1}Department of Energy, and by NSF.

D1.0062 A general approach to few-cycle laser interactions with complex atoms\textsuperscript{1}. XIAOXU GUAN, OLEG ZATSARINNY, KLAUS BARTSCHAT, Drake University, JOHANNES FEIST, Vienna University of Technology (Austria), BARRY SCHNEIDER, National Science Foundation, CLIFF NOBLE, Daresbury Laboratory (U.K.) — We are developing a general method to solve the time-dependent Schrödinger equation for the interaction of a strong laser pulse with a general atom, i.e., beyond the models of quasi-one or quasi-two-electron targets. The field-free hamiltonian matrices are generated in a $B$-spline $R$-matrix method [1], and the laser field is coupled in through dipole matrices generated with the same program. The major advantages of our approach are i) its generality and ii) the possibility of generating highly accurate target descriptions with small configuration interaction expansions. We propagate the solution of the TDSE by the Arnoldi method [2]. The generalized eigenvalue problem is transformed by diagonalizing the overlap matrix $S$ of the non-orthogonal basis functions and generating new field-free hamiltonian and dipole matrix blocks through $H' = S^{-1/2}HS^{-1/2}$ and $D' = S^{-1/2}DS^{-1/2}$. Details of various numerical implementations will be discussed.


\textsuperscript{1}Work supported by the NSF under PHY-0244470 and PHY-0555226.

D1.0063 Creating and manipulating vibrational wavepackets of the $D_1^+$ molecular ion.\textsuperscript{1}. JAR-LATH MCKENNA, CHRIS CALVÉRT, DOMHNALL MURPHY, JIM MCCANN, IAN WILLIAMS, Queens University Belfast, WILLIAM BRYAN, ELIZABETH ENGLISH, JOSEPH WOOD, ROY NEWELL, University College London, EDMOND TURCU, Rutherford Appleton Laboratory — The creation of a vibrational wavepacket within a molecular system shows great promise as an active method of both tracking and controlling nuclear motion on femtosecond timescales. However the coherent excitation of the vibrational eigenstates of the molecule, and the subsequent imaging of the bond vibration, requires pulse durations on the order of the vibrational period. For the theoretically tractable hydrogen molecular ion, such timescales are on the order of 20 fs or less. As such, intense few-cycle infrared laser pulses are required. We present here a study where we excite and subsequently map out the quantum revival of a vibrational wavepacket of $D_1^+$, tracking the nuclear motion over hundreds of femtoseconds. By rigorous modeling of the nuclear motion the experimental results are reproduced to high agreement, and new methods to control both molecular dissociation and vibrational state population are proposed.

\textsuperscript{1}Funding from EPSRC (UK) is gratefully acknowledged.

D1.0064 Wave packet dynamics in doubly excited states of He\textsuperscript{1}. JOHANNES FEIST, STEFAN NAGELE, EMIL PERSSON, JOACHIM BURGDÖRFER, Institute for Theoretical Physics, Vienna University of Technology, 1040 Vienna, Austria, BARRY SCHNEIDER, Physics Division, NSF, Arlington, VA 22230, USA — We have developed a method for the ab initio simulation of the interaction of ultrashort laser pulses with helium atoms. We expand the two-electron Schrödinger equation in spherical harmonics and perform direct time integration utilizing either the Arnoldi-Lanczos or the Leapfrog method. The spatial discretization is performed in an LEDVR basis [1]. This allows for a numerically accurate description while possessing desirable computational features, e.g., a block-diagonal form of the kinetic energy matrix. We will present results on electron-electron correlation and wave packet dynamics in He. By using a suitable combination of attosecond XUV/EUV pulses, we prepare a wave packet in the doubly excited states of helium. The motion of this wave packet can be observed by using a probe pulse to induce ionization. We aim for a detailed understanding of the process by a careful study of the ionized electrons, e.g., by investigating doubly differential momentum spectra.


D1.0065 The dynamics of meta-stable states described with a complex scaled Hamiltonian. EVA LINDROTH, JAKOB BENGTSSSON, SalVE SELSTAD, Stockholm University — The laser development has given access to light pulses in the femto- and subfemtosecond regime and thereby opened the possibility to follow electron dynamics directly in the time domain. Of special interest is the dynamics of resonant states, and pioneering experimental studies were made a few years ago on the Auger decay of inner-shell vacancies. We present a new method for time-dependent calculations of the whole sequence of events when an atom is exposed to a short light pulse followed by the population of a meta-stable state, and with the possibility to follow its subsequent decay by electron ejection. We use the method of complex scaling and show how it can be used together with the time-dependent Schrödinger equation. Important advantages with this approach are; the meta-stable states are obtained as unique eigenstates to the time-dependent Schrödinger equation accurately and efficiently by means of the time- dependent generalized pseudospectral method. We found that the frequency comb structure is preserved within each harmonic. In addition, the repetition frequency of the comb laser depends upon the pulse separation $\tau$ and the spectral width of each individual comb fringe is inversely proportional to the number of pulses $n$ used. However, the overall HHG power spectrum pattern depends only upon the laser frequency and intensity used and is not sensitive to the $\tau$ and $n$ parameters. Finally, the frequency comb structure persists even in the presence of appreciable ionization.

D1.0066 Strong-Field Double Ionization of H$_2$/D$_2$ : Wavelength Dependent Study. IGOR LITVINYUK, Kansas State University, ALI ALNASER, American University of Sharjah, UAE, DANIEL COMTOIS, INRS-Énergie, Matériaux et Télécommunications, ASAD HASAN, American University of Sharjah, UAE, DAVID VILLENEUVE, National Research Council of Canada, JEAN-CLAUDE KIEFFER, INRS-Énergie, Matériaux et Télécommunications — We studied double-ionization of H$_2$ and D$_2$ by intense femtosecond laser pulses of different wavelengths (500, 600, 800, 1300, 2000 nm) and peak intensities. The kinetic energy release (KER) spectra measured in the Coulomb explosion of the molecules were used to identify the various mechanisms responsible for the dissociation and ionization of H$_2$/D$_2$ in the laser fields. In addition to fragments from well known bond softening and enhanced ionization channels, high energy protons/deuterons of KER around 11 eV were for the first time observed when using short wavelengths (500 and 600 nm) at high-peak intensities. This channel exhibited wavelength dependence, with KER decreasing for longer wavelengths. This observation implies that a multiphoton-ionization process is actively operating at short inter-nuclear distances and must be accounted for to correctly understand the strong-field ionization of H$_2$/D$_2$ by short laser pulses.
D1.00067 Study of D$_2$ and H$_2$ nuclear dynamics in strong laser field using Coulomb Explosion Imaging. IRINA BOCHAROVA, IGOR LITVINYUK, LEWIS COCKE, DIPIWITA RAY, CHAKRA MAHARJAN, PREDRAG RANITOVIC, Kansas State University — For small molecules like H$_2$ and D$_2$, most of the nuclear wavepacket motion is expected to occur on femtosecond time scale. To probe such a fast dynamics Coulomb explosion imaging is used in combination with short (8 fs) pulses and pump-probe technique. We use COLTRIMS technique to collect fragments of Coulomb explosion of molecules in coincidence and calculate kinetic energy release of these fragments as well as molecular orientation before the explosion as a function of time. It allows us to track vibration and rotational nuclear wavepackets and follow the dissociation process of hydrogen and deuterium molecules.

D1.00068 Holographic Generation and 3-D Ion Imaging of Focused Ultrashort Pulses of Complex Light$^1$, JAMES STROHABER, CHAD PETERSEN, CORNELIS UITERWAAL, Univ. Nebraska - Lincoln (cuitervaal2@unl.edu) — We investigate an open question in intense-field physics: are excitation and ionization with ultrashort pulses affected by optical orbital angular momentum (OAM)? To answer this question, we holographically create Laguerre-Gaussian paraxial modes, which carry optical OAM. In our experiments we use a computer-controlled spatial light modulator to modulate the transversal profile of 50-fs, 800-nm pulses. Using phase-only masks that also encode the amplitude profile of the desired mode we create µm-sized foci of complex light. We analyze the mode purity of our foci on-site by imaging them with ions, which act as local intensity sensors. We obtain three-dimensional images of the foci without requiring assumptions about their geometry. We also use ion imaging to realize a photo-dynamical test tube, by recording ions created in the ‘hottest’ spot of the focus only, with unsurpassed µm resolution. This allows us to study ionization processes without having to integrate yields over the whole focal region. Finally, we also present a new set of steady-state modes in quadratic lenslike media; these modes are separable solutions in cylindrical parabolic coordinates. Recent progress will be discussed.

D1.00069 Ionization of N$_2^+$ and O$_2^+$ beams in femtosecond intense laser fields.$^1$, A.M. SAYLER, B. Gaire, NORA G. JOHNSON, M. LEONARD, E. PARKE, K.D. CARNES, I. BEN-ITZHAK, J. R. Macdonald Laboratory, Department of Physics, Kansas State University, P.Q. WANG, Department of Physics, Western Illinois University — The dissociative ionization of N$_2^+$ and O$_2^+$ molecular ion beams has been studied using laser pulses of 790 nm, 10-45 fs and up to 2×10$^{15}$ W/cm$^2$. The momentum distributions of the dissociation channels N$^+ +$ N$^+$ and O$^+ +$ O$^+$ are measured by a three-dimensional momentum imaging method. The angular distributions of the ionization of these two molecules exhibit significant differences, which will be compared to theoretical predictions. The angular distribution of the ionization of O$_2^+$ is found to strongly depend on the kinetic energy release. The branching ratios and the intensity dependence of the ionization channels will also be discussed.

D1.00070 Double-Ionization of Ar and Ne in Colors, ALI S. ALNASER, Physics Department-American University of Sharjah, UAE, D. COMTOIS, INRS-Energie, Matériaux et Télécommunications, Varennes, Québec, Canada, A.T. HASAN, Physics Department-American University of Sharjah, UAE, D.M. VILLENEUVE, National Research Council of Canada, Ottawa, Canada, J.-C. KIEFFER, NSR-énergie, Matériaux et Télécommunications, Varennes, Québec, Canada, I.V. LITVINYUK, J.R. Macdonald Laboratory, Physics Department, Kansas State University, USA. — We have conducted a systematic study on the double ionization of Ar and Ne atoms to investigate the origin of the dip in the longitudinal momentum distribution of the doubly-charged recoil ions. We used a wide range of wavelengths (483, 800, 1313, 2016 nm) and laser peak intensities. The momentum distributions of the doubly-charged recoil ions in the direction parallel to the laser polarization were measured with sufficiently high resolution. At 800 nm, Ne$^{2+}$ exhibits a pronounced dip around zero momentum, while Ar$^{2+}$ shows a shallow one. When using the longer wavelengths (1313 and 2016 nm) the dip in the momentum distribution of both ions becomes very distinct, while with the shorter wavelengths the dip gets much shallower in Ne$^{2+}$ and almost disappears in Ar$^{2+}$. Our results indicated that the origin of the dip is principally due to the interplay between the maximum energy gained by the rescattering electron in the laser field and the ionization potential of singly-charged ion.

D1.00071 Extremely short pulses in Maxwell-Duffing model$^1$, UTPAL ROY, Senior Research Fellow, PRASANTA K. PANIGRAHI, Associate Professor — We analyze the reduced Maxwell-Duffing model relevant for ultra short pulse propagation in non-resonant media. We find a wide class of localized pulse solution, through a novel method. It is observed that, these solutions are related to non-linear Schrödinger equation with a complex source. We also find continuous wave solutions. Some of the solutions are singular, indicating self-focusing effect. Modulation instability and stability analysis of the solutions have also been studied.

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

D1.00072 Time-dependent dynamics of intense laser-induced above threshold Coulomb explosion$^1$, B.D. ESRY, I. BEN-ITZHAK, J.R. Macdonald Laboratory, Kansas State University, Manhattan, KS 66506 — We use our recently proposed model$^1$ to extract information about the nuclear dynamics from the recent Coulomb explosion data of Staudte et al. taken with 40 ps pulses$^2$. That data, taken at multiple intensities near the ionization appearance intensity for both H$_2$ and D$_2$, in linearly and circularly polarized light, shows remarkable structure and regularity not easily explained by conventional models. Because our model does fit the spectra well, we can infer the qualitative time-dependent evolution of the system. In addition, we speculate about the possibility of rescattering leading to above threshold Coulomb explosion.

1Supported by the Chemical Sciences, Geosciences and Biosciences Division, Office of Basic Energy Sciences, Office of Science, U.S. Department of Energy.
D1.00073 Progress report on the applications of an ultrafast electron source1, SHAWN HILBERT, BRETT BARWICK, ADAM CAPREZ, CORNELIUS UITERVAAL, HERMAN BATELAAN, University of Nebraska–Lincoln — Femtosecond laser pulses are used to create ultrafast electron pulses from a tungsten nanometer field emission tip. The emission process is rich in features and allows the study of thermionic emission, multi-photon over-barrier emission, ATI-emission, and field induced tunneling [1]. Evidence for the first three processes are presented. The application of the source for interaction between free electrons and laser light [2], and its relation to dispersion compensation for electron wave packets will be discussed. The use of the source to study low energy with high resolution electron physics is presented. The application of the source to investigate the macroscopic limit of the Aharonov-Bohm effect is tested. And finally, attempts to observe diffraction-in-time as a means to probe attosecond physics are reported. [1] Peter Hommelhoff, et al. Phys. Rev. Lett. 97, 247402 (2006), [2] Kapitza-Dirac diffraction without standing waves: diffraction without a grating? O. Smirnova, D. L. Freimund, H. BateLaan, M. Ivanov, Phys. Rev. Lett. 92, 223601/1 (2004).

1This work is supported by the NSF under Grant No. 0354940 and Grant No. 0355235.

D1.00074 Fragmentation of $H_2^+$ molecules irradiated by intense 395 nm femtosecond laser pulses: a coincidence 3D momentum imaging study.1, JARLATH MCKENNA, A. MAX SAYLER, P.Q. WANG, BISHWANATH Gaire, NORA G. JOHNSON, ELI PARKE, F. ANIS, JIANJUN HUA, B.D. ESRY, KEVIN D. CARNES, ITZIK BEN-ITZHAK, J.R. Macdonald Laboratory, Department of Physics, Kansas State University — As the most fundamental molecule, $H_2^+$ is the natural choice of study to understand fast molecular response to intense ($> 10^{12}$ W cm$^{-2}$) short pulse (< 100 fs) laser fields. Previously this molecular ion, prepared as a fast (~10 keV) target, has been explored by our group using a 790 nm Ti:Sapphire laser revealing, for example, interesting structure in the ionization channel attributed to above-threshold Coulomb explosion. Using the second harmonic of this frequency (395 nm light) provides better energy resolution of photon-order dependent processes. As such we present here a coincidence 3D momentum imaging study of $H_2^+$ at this wavelength and compare the results to those using 790 nm light centering the discussion on both the ionization and dissociation channels. A theoretical interpretation of the results is offered.

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

D1.00075 Quantitative comparison between theory and experiment for dissociation of $H_2^+$ in ultrashort laser pulses1, FATIMA ANIS, J. R. Macdonald Laboratory, Department of Physics, Kansas State University, PENGQIAN WANG, Western Illinois University, A. MAX SAYLER, BISHWANATH Gaire, NORA JOHNSON, ELI PARKE, JARLATH MCKENNA, KEVIN CARNES, ITZIK BEN-ITZHAK, BRETT ESRY, J. R. Macdonald Laboratory, Department of Physics, Kansas State University — We have performed calculations for $H_2^+$ dissociation in an intense laser pulse including all possible physical processes except ionization. In particular, we have included nuclear vibration and rotation as well as electronic excitation. We compare these results to data we have obtained from kinematically complete measurements, including both the atomic $H^+$ and neutral H fragments dissociated from an $H_2^+$ beam, achieved through coincidence three-dimensional momentum imaging. To make the comparison as quantitative as possible, we have averaged the theoretical results over Frank-Condon, intensity, and rotational distributions to best match the experimental conditions. Rotational motion in $H_2^+$ is found to be important even for ultrashort pulses ranging from 10-45fs FWHM.

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

D1.00076 Numerical explorations of above threshold Coulomb explosion for H2+ in an intense laser pulse1, JIANJUN HUA, BRETT ESRY. J.R. Macdonald Laboratory, Department of Physics, Kansas State University — Above threshold Coulomb explosion is a mechanism recently invoked by Esry et al. [1] to explain previously unobserved structure in the kinetic energy release (KER) spectrum of intense laser induced ionization of $H_2^+$. Based on a diabatic Floquet-Born-Oppenheimer picture, above threshold Coulomb explosion predicts multiple sequences of peaks separated by a photon’s energy. This model was able to fit the experimental KER data in [1] quite well and allowed predictions about the angular distribution that were also verified in [1]. Nevertheless, fundamental questions about the model remain that we will try to address by solving the time-dependent Schrodinger equation. For simplicity, we solve a one-dimensional model for $H_2^+$ that should retain the physics of above threshold Coulomb explosion. We will discuss the results of this numerical test.

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

D1.00077 RYDBERG AND EXOTIC ATOMS AND MOLECULES —


1Physical Research Laboratory, Ahmedabad, India
D1.00079 Electric Dipole Echoes in Rydberg Atoms

SHUHEI YOSHIDA, Vienna University of Technology, CARLOS REINHOLD, Oak Ridge National Laboratory, JOACHIM BURGDÖRFER, Vienna University of Technology, WEI ZHAO, JEFFREY MESTAYER, JIM LANCASTER, F. BARRY DUNNING, Department of Physics and Astronomy, Rice University — We report the first observation of echoes in the electric dipole moment of an ensemble of Rydberg atoms precessing in an external electric field $F$. Quasi-one-dimensional Rydberg atoms oriented along the $x$ axis are first produced and then subjected to a dc field $F = 20 \text{V/cm}$ that is suddenly applied in the $z$ direction to create a Stark wavepacket whose evolution is monitored using a half-cycle probe pulse. The wavepacket contains states of different $m$ that precess at different rates leading to dephasing. Rapid reversal of the field $F \rightarrow -F$ at $\tau = \pi$ is shown to play the role akin to that of a $\pi$-pulse in NMR in rephasing the dephased ensemble resulting in the build-up of an echo at $t \sim 2\tau$. The appearance of the echo is explained with the aid of classical trajectory Monte Carlo simulations.

1Research supported by the DOE, the NSF, the FWF (Austria), and the Robert A. Welch Foundation.

D1.00080 Ionizing Kicked Hydrogen with Homoclinic Tangles

KORANA BURKE, KEVIN MITCHELL, University of California Merced — A kicked hydrogen atom subjected to alternating periodic forcing by an external electric field exhibits chaotic behavior. We study the geometry of homoclinic tangles that arise in phase space and use the knowledge we gain from the transport of the charged particle through a “turnstile” to draw conclusions about the ionization rate. We apply both delta function and square-shaped alternating kicks to the charged particle. In order to study the escape rate we form the initial conditions by populating an energy eigenstate or a minimum uncertainty wavepacket. We examine the lobe dynamics and give conclusions about how the size and shape of the lobes influence the phase space transport. The classical calculations can be applied to the study of ionization rates of highly excited Rydberg atoms.

D1.00081 A study of adiabatic population transfer for the production of heavy Rydberg systems

JEFFREY PHILIPPION, RALPH SHIEL, Trent University — We present recent progress towards the production of heavy Rydberg systems within alkali metal dimers using STIRAP to effect vibrational state transfer followed by excitation with a pulsed UV laser. We have calculated the efficiency of adiabatic population transfer in a 2-level system and investigated its dependence on the temporal profile of the perturbation. We show that the optimal profile for adiabatic following results in a significantly lower probability of a non-adiabatic transition than that predicted by applying the Landau-Zener formula. We have also determined the relationship between population-loss and beam profile for a 3-level system undergoing a STIRAP process. These theoretical predictions will be compared with results from a molecular beam experiment within which lithium dimers cross beams from a pair of diode lasers tuned to the $A^1\Sigma_u^+ - X^1\Sigma_g^+$ transition.

1This work is supported by the NSF

D1.00082 Non-Degenerate Four-Wave Mixing through Rydberg States in a MOT

JASON DAY, ERIK BREKKE, THAD WALKER, University of Wisconsin-Madison — In this work, we use a three-photon near-resonant process in a laser-cooled Rb vapor to achieve phase-matched four-wave mixing using an intermediate Rydberg state. Rydberg atoms in the 3D5/2 state are efficiently produced using a 780 nm/480 nm two-photon excitation detuned 500 MHz above the 5P3/2 intermediate state. When a 1019 nm laser stimulates emission down to the 6P3/2 state, the Rydberg atom populations are significantly depleted and 422 nm 6P3/2-5S photons are observed by photon-counting photomultiplier tubes. With the 780 nm, 480 nm, and 1019 nm lasers configured in a non-collinear phase-matched geometry, we observe a coherent 422 nm phase-matched signal that is up to 10 times larger than the non-phase-matched radiation. Under these phase-matched conditions, the incoherent radiation is partially depleted. These experiments demonstrate the ability to coherently manipulate ultracold atoms at optical frequencies using Rydberg states.

D1.00083 Rydberg Ion Fine Structure Measurements with the RESIS Method

C.W. FEHRENBACK, Kansas State University, S.R. LUNDEEN, Colorado State University — Measurements of Rydberg fine structure provide precise determinations of positive ion properties such as polarizabilities and permanent moments. The Resonant Excitation Stark Ionization Spectroscopy (RESIS) method, which has provided a range of such measurements in neutral atoms and molecules [1], has recently been extended to study of Rydberg ion fine structure. In principal, the method can be applied to study positive ions of arbitrary charge. The factors limiting signal to noise and frequency resolution in measurements of this type will be discussed, and some possible future applications will be described. [1] S.R. Lundeen in Advances in Atomic, Molecular, and Optical Physics, edited by Chun C. Lin and Paul Berman (Academic Press, 2005), Vol 52, pp. 161-208

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

D1.00084 Rydberg tagging time-of-flight imaging to study ultracold collisions

JONATHAN TALLANT, K. RICHARD OVERSTREET, ARNE SCHWETTMANN, JAMES P. SHAFFER, University of Oklahoma — We have further developed Rydberg tagging time-of-flight and imaging techniques so that they can effectively be used to study ultracold collisions. We have realized a velocity resolution of $\sim 1.2 \text{cm/s}$ with our apparatus. This resolution enables Rydberg tagging time-of-flight and imaging spectroscopy to determine the exit channel of an ultracold collision. Results and prospects for applying these methods to measure differential cross-sections for Rydberg atom collisions, photoassociative collisions, and three-body recombination will be presented.

1We acknowledge funding from the Research Corporation, the OSRHE and the Air Force Office of Scientific Research (FA9550-05-0328).

D1.00085 Efficient broadband de-excitation of Rydberg atoms with half-cycle pulses

KOUROSH AFROUSHEH, ANDREW SPECK, Rowland Institute at Harvard — We report on progress towards demonstrating population redistribution of Rydberg atoms using a train of unipolar terahertz bandwidth pulses (half-cycle pulses) as initially proposed by Hu and Collins [1]. In principle this broadband technique should allow the efficient de-excitation of antihydrogen atoms from the currently produced mix of excited states to the ground state which is a necessary prerequisite for a CPT comparison with hydrogen. Here a cloud of ultracold $^3$H atoms are excited to a Rydberg state with $n \approx 40$, allowed to interact with an 80 MHz pulse train of half-cycle pulses, and then the final state distribution is measured. Initial demonstrations of the techniques used for the generation of half-cycle pulses and Rydberg atom redistribution will be described.


D1.00086 Angular Studies of Xenon Rydberg Atom Ionization at Au(111) Surfaces

H.R. DUNHAM, D.D. NEUFELD, J.C. LANCASTER, Rice University, S. WETHKAM, Universität zu Berlin, F.B. DUNNING, Rice University — The ionization of xenon atoms excited to the lowest states in the $n = 17$ and $n = 20$ Stark manifolds at a flat Au(111) surface is being examined over a range of incident angles. The data suggest that, despite the strong perturbations in the energies and structure of the atomic states that occur as the surface is approached, the experimental data can be well fit by assuming that the ionization rate on average increases exponentially as the surface is approached. Under appropriate conditions, each incident atom can be detected as an ion and the inferred mean ionization distances are in reasonable agreement with theoretical predictions.

1Research supported by the NSF and the Robert A. Welch Foundation.
D1.00087 Ionization of xenon Rydberg atoms at oxidized Si(100) surfaces\(^1\). DENNIS NEUFELD, HARDIN DUNHAM, JIM LANCASTER, BARRY DUNNING, Rice University, STEPHAN WETHEKAM, Institut für Physik der Humboldt-Universität zu Berlin — The ionization of xenon Rydberg atoms incident at near grazing angles on an oxidized Si(100) surface is being examined. Comparison to earlier measurements at a Au(111) surface suggests that ionization, i.e., electron tunneling, occurs much further from the surface and at atom-surface separations that are physically unreasonable. A number of possible explanations for these observations have been considered including both ion reflection and the presence of stray electric fields at the surface. Model calculations suggest that even relatively small variations in surface potential due, for example, to surface charging can lead to the generation of strong local fields sufficient to field ionize the incident atoms before tunneling occurs. This effect is discussed together with possible applications in the detection of low-\(n\) Rydberg atoms.

\(^1\)Research supported by the NSF and Robert A. Welch Foundation.

D1.00088 Resonance states with unnatural parity in the \((e^+\text{-He}^+)\) system\(^2\), Z.-C. YAN, University of New Brunswick, Canada, Y.K. HO, Institute of Atomic and Molecular Sciences, Academia Sinica, Taipei, Taiwan, ROC — Bhattacharyya and Drachman reported two \(S\)-wave resonances in positron scattering by a helium ion \((\text{He}^+)\)\(^1\). Since then, there has been considerable interest in the investigation of the resonances for this system\(^2\). In these works resonances with natural parity were investigated. In the present work, we apply the method of complex-coordinate rotation to investigate resonances with unnatural parity in the positronium-helium-ion system. We have calculated some \(P^\pm, D^\pm, F^\pm, G^\pm\), and \(H^\pm\) resonance states using highly correlated Hylleraas-type wave functions\(^3\). While such resonances cannot be reached by positron collision with the ground state helium ion, they can be reached, in principle, by positron scattering with the helium ion in one of its excited states.\(^1\) A.K. Bhatia and R. J. Drachman, Phys. Rev. A \textbf{42}, 5117 (1990).\(^2\) Y.K. Ho, Phys. Rev. A \textbf{53}, 3165 (1996); Y.K. Ho and Z.-C. Yan, Phys. Rev. A \textbf{66}, 062705 (2002); A. Igarashi and I. Shimamura, Phys. Rev. A \textbf{70}, 012706 (2004); Nobuhiro Yamanaka \textit{et al}, Phys. Rev. A \textbf{70}, 062701 (2004).\(^4\) Z.-C. Yan and G. W. F. Drake, \textit{Chem. Phys. Lett.} \textbf{259}, 96 (1996).

\(^2\)ZCY is supported by NSERC of Canada. YKH is supported by NSC of ROC.

D1.00089 Diode pumped continuous wave Cs vapor laser with 10W output, RANDALL KINIZE, BORIS ZHDANOV — We have demonstrated an efficient Cesium vapor laser pumped by a continuous wave narrowband Laser Diode Array (LDA). To obtain a high efficiency, it is necessary to narrow the linewidth of the LDA pump radiation to match the Cs atom absorption line. At a buffer gas pressure close to 1 atm the Cs absorption linewidth is about 15 GHz, which is much less than typical linewidth of commercially available LDAs (about 1 THz). An external cavity with wavelength sensitive narrowband filter was used to narrow an LDA linewidth to below 1 GHz. A heated 2 mm Cs cell with 500 torr ethane was assembled inside a half confocal laser cavity. The spatially multimode pump beam was focused into the cell. The experiment yielded about 10 W output power at 25 W pump power. The Cs vapor laser operated at 894 nm in single longitudinal and fundamental transverse modes. The developed laser can be used for laser cooling experiments. We acknowledge support from NSF, AFOSR and JTO-HELV.

D1.00090 COLLISIONS OF ATOMS WITH ATOMS, ANTIMATTER, MOLECULES, CLUSTERS, AND SURFACES —

D1.00091 Method to compute wave function evolution from microscopic to macroscopic distances, JAMES STERNBERG, University of Tennessee — The treatment of loosely bound and continuum electrons in atomic collisions has provided challenges for calculations of these systems. These challenges have not been fully overcome for ion-atom collisions since electron wave functions evolve from microscopic to macroscopic distances. One major source of difficulty is that solutions to the time-dependent Schrödinger equation contain an essential singularity at infinity which makes numerical modeling of these systems difficult for large distances. We have identified this essential singularity and developed a method to treat these systems which is extremely efficient and stable. The method is Gallelian invariant, which avoids any ambiguity about what the proper frame of reference should be. It also avoids numerical inaccuracies induced by reflection or absorption at finite boundaries. Wave functions can easily be propagated out to macroscopic distances instead of only approximately 100 au. Finally, the results are consistent with the hidden crossing theory at low impact energies and the Born theory at high energies. In both regimes the electron distribution agree qualitatively with experiment.

D1.00092 Resonance structure in the dipositronium molecule, JOSEPH DI RIENZI, College of Notre Dame of Maryland, RICHARD DRACHMAN, NASA-Goddard Space Flight Center — We are investigating the resonances, first reported by Adhikari\(^1\), occurring in the scattering of pairs of positronium atoms. In particular, we are testing the hypothesis that these resonances occur at energies corresponding to “bound” states of the positronium ion (either positive or negative) and an electron or positron, respectively. The potential producing the binding is Coulombic at large distances and modified at small distances. Such a model was successful in the analogous case of Ps-H scattering\(^2\), and it would be interesting if it also worked in the present case. A complication in the dipositronium system is that the two positive particles (positrons) are identical, whereas in the Ps-H case the spatially multimode pump beam was focused into the cell. The experiment yielded about 10 W output power at 25 W pump power. The Cs vapor laser operated at 894 nm in single longitudinal and fundamental transverse modes. The developed laser can be used for laser cooling experiments. We acknowledge support from NSF, AFOSR and JTO-HELV.

D1.00093 Near Threshold Positron Ionization of Hydrogen, KRISTA JANSEN, S.J. WARD, University of North Texas, J. SHERTZER, College of the Holy Cross, J.H. MÁÈEK, University of Tennessee — The hyperspherical hidden crossing method is used to calculate the ionization cross section for \(e^+\text{-H}\) near threshold. The Wannier ridge for positron impact ionization corresponds to a co-linear arrangement with the electron between the positron and proton and \(r_- / r_+ = .4643\). The adiabatic Hamiltonian for total angular momentum zero is expanded about the saddle point and the analytic adiabatic energies are used to obtain the threshold law for breakup: \(\sigma(E) \propto E^{2.64} \exp\left(-0.49\sqrt{E}\right)\). Our results are consistent with the previous values of the Wannier exponent\(^4\) and the second order correction terms to the threshold law\(^2\). Using our numerical results for the transition probability in the interaction region, we calculated the absolute \(S\)-wave ionization cross section. \(^5\)H. Klar, J. Phys. B \textbf{14}, 4165 (1981). \(^6\)W. Ibra et al., Phys. Rev. Lett. \textbf{78}, 4027 (1997). \(^7\)J. Sternberg et al., Bull. Am. Phys. Soc. \textbf{49}, 52 (2004).

D1.00094 Generalized polarizabilities of Ps negative ion, ANAND BHATIA, RICHARD DRACHMAN, NASA/Goddard Space Flight Center — The positronium negative ion, consisting of two electrons and a positron, is particle stable and decays only by \(e^+\) and \(e^-\) annihilation into gamma rays. In the past, we have calculated various properties like ground state\(^1\) energy, decay rate, and photodetachment cross sections. The latter could be used to generate positronium (Ps) beams of controlled energy by acceleration of the Ps negative ion and then photodetaching one of the electrons. A possible type of metastable excited state of the dipositronium molecule (Ps\(_2\)) has the form of a Ps\(^-\) and a positron in a Rydberg state. Although the modified Coulomb potential will account for most of the binding energy, for high \(L\) states the generalized polarizabilities \([\alpha_L, \beta_L, \gamma_L, i=1,2]\) will contribute small but significant energy shifts. We calculate these quantities by the pseudostate method. Ps\(^-\), a loosely bound system, has very large polarizabilities as compared to those of the hydrogen ion (H\(^-\)) and the helium atom.
D1.00095 Electron and positron scattering experiments. JAMES SULLIVAN, RSphysSE, Australian National University, ADRIC JONES, PETER CARADONNA, ANDREW MANNING, TERRANCE SAK, STEPHEN BUCKMAN, CENTRE FOR ANTIMATTER-MATTER STUDIES COLLABORATION — The final commissioning of the Australian Positron Beamline Facility is almost complete, and it is anticipated that the first experimental results for positron scattering will be obtained this year. In addition, a novel electron scattering experiment has been constructed making use of the same scattering techniques. While the APBF uses a Surko trap to generate a cold, pulsed positron beam, the new electron scattering experiment makes use of thermionic emission and a pulsed electrode to make a similarly pulsed electron beam. By using a retarding potential difference technique, the energy spread of the electrons is able to be reduced compared from the initial distribution from the filament before being directed to a scattering cell. The scattering and analysis is the same as that for the Surko scheme, but due to the compact nature of the electron source, the experiment is highly compact and correspondingly inexpensive. This poster will present the current state-of-play with the positron scattering program at the ANU, along with a detailed explanation of the construction and operation of a cheap, yet effective, experiment to perform electron scattering measurements. An outline of the proposed experimental program for both apparatus will also be given.

D1.00096 Comparisons of Differential Double Ionization of Ar by Positron and Electron Impact1. O.G. DE LUCIO, J. GAVIN, R.D. DUBOIS, University of Missouri-Rolla, Rolla, MO 65409, A.C.F. SANTOS, Instituto de Fisica, Universidad Federal do Rio de Janeiro, Cx Posta Postal 68528, 21941-972 Rio de Janeiro, RJ, Brazil — Differential cross sections for single and multiple ionization of argon by 500 eV positrons and electrons are being measured. The goal of this work is to investigate projectile charge effects in the ionization kinematics. Using coincidences between projectiles which have lost specific amounts of energy and recoil ions, ratios of double to single ionization as a function of energy loss were studied. These data are being used to investigate interference between the TS1 and TS2 terms leading to double ionization. Using coincidences between ejected electrons and recoil ions, angular distributions for electron emission resulting from single and multiple ionization were studied. Ratios of the angular distributions provide insight into the relative importance of the TS1 and TS2 mechanism for double ionization. Initial analysis implies differences for positron and electron impact.

1This work was supported by NSF.

D1.00097 A Proposed Apparatus for Efficiently Trapping and Cooling Positrons.1, JASON ENG-BRECHT, DANIEL ENDEAN, St. Olaf College — Previous work has shown the ability to trap positrons efficiently for long periods of times using a Penning trap. Utilizing strategically placed electrostatic wells, axial energy is transferred into cyclotron energy temporarily trapping the positrons. Combined with a ramping potential on one end of the trap, trapping times of a few ms with efficiencies of approximate 20% were achieved to produce a beam with a high energy spread (~100 eV). We have developed a simulation of this system for the purpose of studying its dynamics. From this simulation we have discovered the role of resonance between the cyclotron orbit and the length of the potential well. We have also examined the potential for a newly optimized trap based on this design that implements gas or electronic cooling to reduce the energy spread of the positrons.

D1.00098 Inelastic Transitions in Slow Collisions of Anti-Hydrogen with Hydrogen Atoms1. ROBERT HARRISON, PREDRAG KRSTIC, Oak Ridge National Laboratory — We calculate excited adiabatic states and nonadiabatic coupling matrix elements of a quasimolecular system containing hydrogen and anti-hydrogen atoms, for a range of internuclear distances from 0.2 to 20 Bohrs. High accuracy is achieved by direct diagonalization of the molecular Hamiltonian in a large Gaussian basis. Nonadiabatic dynamics was calculated by solving MOCC equations. Positronium states are included in the consideration.

1We acknowledge support of the U.S. DoE under contract No. DE-AC05-00OR22725 with UT-Battelle, LLC.

D1.00099 Positron scattering on highly excited antihydrogen atom in strong magnetic field. D. VRINCEANU, Los Alamos National Laboratory, T. POHL, H.R. SADEGHPOUR, ITAMP, Harvard-Smithsonian Center for Astrophysics — Classical Trajectory Monte Carlo simulation technique is employed to study the collision of a positron on highly excited antihydrogen atom in conditions similar to Penning trap experiments. The main difficulty is generating a distribution of initial conditions which describes accurately an atom of given energy and angular momentum projection in strong magnetic field. The quality of the non-perturbative ensemble proposed here is verified by calculating, and comparing, various average quantities in both classical and quantum mechanical ways. The results for energy and angular momentum transfer are presented for a wide range of positron projectile energies.

D1.00100 Cooling by Spontaneous Decay of Highly Excited Antihydrogen Atoms in Magnetic Traps. THOMAS POHL, HOSEIN R. SADEGHPOUR, ITAMP, Harvard-Smithsonian Center for Astrophysics, Cambridge, MA, YUGO NAGATA, Institute of Physics, University of Tokyo, Japan, YASUNORI YAMAZAKI, Atomic Physics Laboratory, RIKEN, Japan — An efficient cooling mechanism of magnetically trapped, highly excited antihydrogen atoms is presented. This cooling, in addition to the expected evaporative cooling, results in trapping of a large number of atoms in the ground state, essential for future antihydrogen trapping experiments. In good agreement with our numerical simulations, we identify two different dynamical regimes - adiabatic cooling followed by sudden de-excitation. Moreover we derive expressions for the cooling efficiency, which may help to design trap geometries with optimized groundstate trapping.

D1.00101 First principles study of adsorption and dissociation of H2, O2, and CO on Pt and Pt-Co clusters.1, T. J. DHILIP KUMAR, CHENGGANG ZHOU, BALAKRISHNAN NADUVALATH, Department of Chemistry, University of Nevada Las Vegas, NV 89154, ROBERT C. FORREY, Department of Physics, Penn State University, Berks-Lehigh Valley College, Reading, PA 19610, HANSONG CHENG, Airproducts and Chemicals Inc., 7201 Hamilton Boulevard, Allentown, PA 18195 — Pt and Pt based alloy nanoparticles have received much attention recently in designing improved catalysts for the oxygen reduction reaction in fuel cell electrodes. To gain physical insight into the catalytic properties of Pt and Pt-Co alloys we have performed fundamental studies on Pt1 and Pt1-Co alloy clusters using first principles density functional calculations. The structural and physicochemical properties of the pure metal and the alloy have been analyzed, and for Pt4, the tetrahedral geometry is found to be more stable than the square planar geometry. On the optimized tetrahedral geometries the interactions of H2, O2, and CO with different orientations have been studied. The calculated energies of adsorption indicate H2 and CO prefers to adsorb on Pt atom while O2 prefers Co atom. The adsorption energy of CO is found to be the highest of all the three adsorbing species in both pure Pt and Pt-Co alloy clusters.

1This work is supported by DOE grant No. DE-FG36-05GO85028.
D1.00102 Resonant charge transfer in H\textsuperscript{−} ions scattering off Si(100) surfaces, BOYAN OBRESKOV. UWE THUMM, Dept. of Physics, Kansas State University — We present numerical calculations on the one-electron charge exchange between an unconstructed Si(100) surface and H\textsuperscript{−} ions that are incident at kinetic energies of 1 keV. The ground state electronic structure of the surface is derived within a self-consistent screened pseudopotential Thomas-Fermi method. Si crystal wave functions and energies of the electron states that this potential holds are calculated by solving one-particle Schrödinger equations. Resonant charge transfer ion-surface couplings are derived, and Neum-Anderson model is solved within a self-energy method. The neutralization probability of the anion after the collision is calculated and compared with available experimental data of [1].


Supported by NSF and the Division of Chemical Sciences, Office of BES, Office of Energy, US DOE.

D1.00103 “Step-up” vs. “Step-down” scattering asymmetry in the charge transfer of H\textsuperscript{−} on free-electron vicinal metallic surfaces, BOYAN OBRESKOV. UWE THUMM, Dept. of Physics, Kansas State University — We present numerical results based on a wave-packet propagation study of the one-electron charge transfer between H\textsuperscript{−} ions and free-electron vicinal metallic surfaces [1]. We derive an effective potential for the motion of the active electron within a Thomas-Fermi-von Weizsäcker model and extend this model to include the image charge effects. We first calculate H\textsuperscript{−} affinity level shift and width in fixed-ion approximation and solve a rate equation for the ion-survival probability for projectiles that are incident with a kinetic energy of 50 eV. We find an enhancement of the electron loss near the steps of the surface, due to the Smoluchowski effect. As a consequence, the ion-survival is more likely if the projectiles approach steps from above than from below [2].


Supported by NSF and the Division of Chemical Sciences, Office of Basic Energy Sciences, Office of Energy Research, US DoE.

D1.00104 Three-state Feshbach resonances in the presence of external fields, CHRISTOPHER HEMMING, ROMAN KREMS, University of British Columbia — We present an analytical analysis of Feshbach resonances involving three states in heteronuclear atom-atom collisions in the presence of external static electric and magnetic fields. The Hamiltonian of study involves a resonant coupling between a p-wave continuum state and a bound molecular state and a coupling between an s-wave continuum state and the p-wave continuum state. There is no direct coupling between the s-wave scattering state and the bound state of the dimer. The dependence of elastic s-wave scattering on the s-p and p-bound couplings is described.

D1.00105 Calculation of the dispersion interaction between two atoms\textsuperscript{1}, J. Y. ZHANG, J. MITROY, Faculty of Technology, Charles Darwin University, Darwin NT 0909, Australia, M. W. J. BROMLEY, Department of Physics, San Diego State University, San Diego, CA 92182 USA — A general procedure for systematically evaluating the long range interaction between two hetero-nuclear atoms in arbitrary states is outlined. The \( C_6 \), \( C_8 \) and \( C_{10} \) dispersion coefficients for the excited states of a number of alkali and alkaline atoms interacting with H and He are evaluated. One useful result concerns the lowest order \( C_6 \) coefficient for a pair of hetero-nuclear atoms. This can always be written in terms of sum rules only involving the oscillator strength. In addition, the coefficients for the long-range interaction between two homo-nuclear lithium atoms in a variety of excited states are presented.

\textsuperscript{1}This work is supported in part by the Australian Research Council.

D1.00106 Non-adiabatic coupling in cold collisions of spin-polarized metastable hydrogen atoms\textsuperscript{1}, ROBERT C. FORREY, Department of Physics, Pennsylvania State University at Berks, ALEX DALGARNO, Harvard-Smithsonian Center for Astrophysics, YULIAN V. VANNE, ALEJANDRO SAENZ, AG Moderne Optik, Institut fuer Physik, Humboldt-Universitaet zu Berlin, PIOTR FROELICH, Department of Quantum Chemistry, Uppsala University — Previous calculations of low temperature cross sections for collisions between metastable hydrogen atoms are improved to include non-adiabatic radial and angular coupling. The electrostatic dipole-quadrupole interaction produces non-adiabatic radial coupling between (2s,2p) and (2p,2p) states while the Coriolis interaction produces non-adiabatic angular coupling. Both of these long-range interactions are handled in a space-fixed atomic gauge that is particularly convenient for a spin-polarized system. The improved theoretical results are compared with an existing experiment.

\textsuperscript{1}supported by NSF grant No. PHY-0554794.

D1.00107 H\textsubscript{2} dissociation due to collision with He\textsuperscript{1}, ROBERT C. FORREY, Department of Physics, Pennsylvania State University at Berks, N. BALAKRISHNAN, Department of Chemistry, University of Nevada-Las Vegas, TECK-GHEE LEE, Department of Physics and Astronomy, University of Kentucky, and Physics Division, Oak Ridge National Laboratory, PHILLIP STANCIL, Department of Physics and Astronomy, and Center for Simulational Physics, University of Georgia — Cross sections for dissociation of H\textsubscript{2} due to collision with He are calculated for excited rovibrational states using the quantum mechanical coupled states approximation. An \( L^2 \) Sturmian basis set with multiple length scales is used to provide a discrete representation of the H\textsubscript{2} continuum which includes orbiting resonances and a non-resonant background. Cross sections are given over a range of translational energies for resonant and non-resonant dissociation together with the most important bound state transitions for four different initial states. The results demonstrate that it is possible to compute converged quantum mechanical cross sections using basis sets of modest size.

\textsuperscript{1}supported by the NASA Spitzer Space Telescope Theoretical Research Program

D1.00108 Close-coupling study of rotational energy transfer in H\textsubscript{2}O collisions with He atoms\textsuperscript{1}, BENHUI YANG, PHILLIP STANCIL, University of Georgia, DEPARTMENT OF PHYSICS AND ASTRONOMY TEAM — Due to the astrophysical importance of water and helium, the H\textsubscript{2}O-He collisional system has been the subject of numerous experimental and theoretical studies. For numerical astrophysical models, quantitative determinations of state-to-state cross sections and rate coefficients for H\textsubscript{2}O-He collisions are crucial. In this work quantum close-coupling scattering calculations of rotational energy transfer (RET) of rotationally excited H\textsubscript{2}O due to collisions with He are presented for collision energies between \( 10^{-6} \) and \( 1000 \) cm\textsuperscript{-1} with para-H\textsubscript{2}O initially in levels \( 1_j, 2_j, 3_j, 2_j, 0_0 \), and ortho-H\textsubscript{2}O in levels \( 1_j, 2_j, 2_j, 2_j \). Differential cross section, quenching cross sections and rate coefficients for state-to-state RET were computed on three new H\textsubscript{2}O-He potential energy surfaces (PESs). The inelastic and elastic differential cross sections are also compared with available experimental measurements.

\textsuperscript{1}We acknowledge support from NASA grant NNG04GM59G.
D1.00110 A Two-Atom Relaxation-Theory Approach to Understanding Non-Markovian Dynamics in Dense Atomic Gases\textsuperscript{1}, JOSH W. DUNN, CHRIS H. GREENE, Department of Physics and JILA, University of Colorado, Boulder, CO 80309-0440 — Relaxation theory, based on detailed treatment of atomic scattering, has in the past provided an elegant formalism \cite{1} and yielded accurate predictions of experimental collisional-broadening data \cite{2}. Recent experiments have utilized sophisticated transient four-wave-mixing techniques to probe interactions in dense atomic gases, and the use of fast lasers to create probe pulses allows for atomic collisions to be explored on a timescale shorter than the dephasing time of the gas \cite{3}. We present a theoretical description of such phenomena that extends the relaxation-theory treatments beyond the regime of static collision broadening to incorporate the dynamical effects of transient photon-echo pulses. Beginning with a realistic description of two-atom scattering, we are able to calculate the nonlinear response function for the system, a quantity which can be compared with experimental photon-echo data. \cite{1} U. Fano, Phys. Rev. 131, 259 (1963). \cite{2} A. Ben-Reuven, Phys. Rev. 145, 7 (1966). \cite{3} V. O. Lorenz and S. T. Cundiff, Phys. Rev. Lett 95, 163001 (2005).

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

D1.00110 SURFACE PLASMONS

D1.00111 Single-photon nonlinear optics with nano-scale surface plasmons, DARRICK CHANG, Harvard University, ANDERS SORENSEN, Niels Bohr Institute, VLADIMIR GRITSEV, EUGENE DEMLER, MIKHAIL LUKIN, Harvard University — We explore nonlinear optical phenomena in systems that support a set of tightly-confined, one-dimensional electromagnetic modes. Among the physical systems of interest are guided surface plasmons propagating on conducting nano-structures and hollow-core photonic crystal fibers. The tight transverse confinement of the modes enables a large emitter-field coupling strength and the possibility of nonlinear optics down to a single-photon level. Several novel applications are presented. First, we demonstrate how the interaction between a single photon and either a single emitter or ensemble can be controlled to create a high-fidelity, state-dependent mirror. The state-dependent mirror can be used, for example, to implement a controlled-phase gate between photons or an all-optical, single-photon transistor. Connections to condensed-matter systems such as the Kondo Hamiltonian and Luttinger liquid are also discussed.

D1.00112 Strong coupling of single optical emitters to nano-scale surface plasmons, ARYESH MUKHERJEE, Harvard University, ALEXEK AKIMOV, Harvard University, P.N. Lebedev Physical Institute, ALEXANDER ZIBROV, DARRICK CHANG, Harvard University, ANDERS SORENSEN, Niels Bohr Institute, CHUN YU, HONGKUN PARK, Harvard University, PHILIP HEMMER, Harvard University, Texas A&M University, MIKHAIL LUKIN, Harvard University — We present an experimental observation of strong optical coupling between individual, nanocrystal CdSe/ZnS quantum dots and the guided surface plasmon modes of a proximal silver nanowire. The strong coupling between emitter and field is enabled by the unique properties of the plasmon modes on these nanowires. In particular, due to the small size of the nanowires (\sim 100 nm in diameter), the surface plasmons are localized transversely to dimensions well below the diffraction limit. An enhancement of the Purcell factor of the system and photon correlations consistent with a single-photon source are observed, and a realistic theoretical model for these processes is presented.

D1.00113 Quantum Electrodynamics of Surface Plasmons, JEREMIE CHOQUETTE, PETER MARZLIN, RENE STOCK, BARRY SANDERS, IQIS, University of Calgary — Surface plasmons are electromagnetically induced charge-density waves that appear at the interface between dielectrics and a thin metal film and can enhance optical field intensities by two to three orders of magnitude. Despite their fast decay surface plasmons have been shown to preserve optical entanglement and may be useful for optical quantum information. We present a detailed theoretical analysis of the interaction of photons and atoms in the presence of a dielectric interface permitting surface plasmons. We use a Green’s function technique to quantize the electromagnetic field in planarly multi-layered lossy and absorbing dielectrics to give an accurate description of the noise induced near the metal film. We calculate the modified spontaneous emission rate of an atom near the interface and study the radiation characteristics of the emitted light. Furthermore we analyze the propagation of a single photon pulse through the interface. We discuss applications of our results to enhance nonlinear effects in quantum optics.

D1.00114 ATOM MOTION/MATTER WAVE INTERFEROMETRY

D1.00115 Monte Carlo Simulation of Spontaneous Emission from Dressed States\textsuperscript{1}, B. BARRETT, S. BEATTIE, A. KUMARAKRISHNAN, York University, YORK UNIVERSITY TEAM — It is well known that atomic states coupled with the photon field can be described by the dressed state basis. In previous work (J. Opt. Soc. Am. B 2, 1707, Phys. Rev. A 47, 2128) the atomic density matrix elements have been modeled in the dressed state basis, from which the spontaneous emission rates from dressed states can be calculated. We use this treatment to model the results of a recent experiment that uses a single state atom interferometer and laser cooled \textsuperscript{85}Rb atoms. The effective spontaneous emission rate measured in the experiment shows a monotonic increase as a function of “interaction time”—the time atoms are subjected to standing wave laser pulses. We describe the details of the experiment and a Monte Carlo simulation of spontaneous emission from dressed states in a standing wave to explain the results. The results of the simulation show qualitative agreement with the experiment and suggest that the origin of the effect is related to the variation of the spontaneous emission rate in the standing wave potential and the spatial profile of the laser beams.

\textsuperscript{1}Work supported by CFI, OIT, NSERC, OCE and York University

D1.00116 Electron Coherence Length Measurement Using Nanogratings, BEN MCMORRAN, ALEX CRONIN, University of Arizona — We have measured the transverse coherence length of an electron beam using an electron interferometer constructed of two nanostripe gratings and an imaging detector\textsuperscript{1}. When one of the gratings is twisted about the optical axis the visibility of the Lau fringes decreases. This dependence is predicted by a theory that assumes a semi-coherent converging beam. When splitting a curved wavepacket, either under instantaneous momentum transfer, or when the wavepacket is split using adiabatically raised potentials. We also present a simple classical model for the resultant amount of excitation which is valid for a range of experimentally accessible conditions.

D1.00117 Bose-Einstein condensates and their bright solitons in circular waveguides, MARTIN D. KANDES, OSCAR O. SALAZAR, MICHAEL W.J. BROMLEY, Department of Physics, San Diego State University, RICARDO CARRETERO-GONZALEZ, Department of Mathematics and Statistics, San Diego State University, BRETT D. ESRY, Department of Physics, Kansas State University — Following the recent trapping and propagation of Bose-Einstein condensates around circular waveguides, we present theoretical results exploring some possible issues that may arise in future Sagnac interferometry experiments, particularly when perfect rings are tilted in gravity. We employ, firstly, a 1-D mean-field model to compare and contrast the interference observed when counterpropagating either BEC’s, or continuously dispersion managed BEC’s, or gap solitons. Secondly, we use 2-D simulations to determine the transverse excitations induced when splitting a curved wavepacket, either under instantaneous momentum transfer, or when the wavepacket is split using adiabatically raised potentials. We also present a simple classical model for the resultant amount of excitation which is valid for a range of experimentally accessible conditions.
D1.00118 Sensitivity and accuracy studies of an atomic gravimeter, JULIEN LE GOÛT, CNRS, Observatoire de Paris — Atom interferometry is used to perform an absolute measurement of the gravitational acceleration \(g\) with \(^{87}\text{Rb}\) free falling cold atoms. A sequence of three stimulated Raman transitions separates and recombines the atomic wave function, using vertical counter-propagating lasers. During each light pulse, the phase difference of the lasers is imprinted onto the atomic phase. The phase shift between the two paths depends on \(g\), and scales with the square of the time interval between two consecutive pulses. As our experiment was developed to be transportable, the maximum interaction time is limited to 120 ms, but has a high repetition rate of up to 5 Hz. By combining passive isolation and post-treatment of the vibrations measurement, we reach a sensitivity better than \(2 \times 10^{-6} g/Hz^{1/2}\). The contribution of the lasers to the phase noise of the interferometer is negligible, as it limits the sensitivity to \(3 \times 10^{-8} g/Hz^{1/2}\). We pointed out a generally neglected effect due to the retro-reflection delay, which could represent a limitation to the sensitivity of atomic gradiometers. I will also detail our investigations of the various systematic effects that shift the measured value of \(g\). Alternating measurements with opposite directions of the Raman lasers allows to reject shifts due to one photon light shift, RF phase shifts, as well as magnetic field gradients (rejection at the \(10^{-3}\) level). The influence of two photon light shift, wavefront distortions and Coriolis acceleration will be discussed too.

D1.00119 Enabling Chip-Based Atom Interferometer I: Long Coherence Time and Number Squeezing with \(^{23}\)Na BECs, C.A. CHRISTENSEN, G.-B. JO, Y. SHIN, S. WILL, T.A. PASQUINI, M. SABA, W. KETTERLE, D.E. PRITCHARD, MIT — Using a combination of DC and RF magnetic fields, we have coherently split a BEC into two separated BECs on an atom chip. We find that the split BECs maintain a relative phase coherence for up to 200 ms, which we read out using absorption imaging of matter wave interference after time-of-flight expansion. This is a factor of 10 longer than the phase diffusion time for a coherent state at our atom number and density. We attribute the long coherence time to number squeezing by a factor of 10 caused by mean-field interactions during the splitting process, which reduces the phase diffusion rate. In spite of the presence of strong atom-atom interactions, the system potentially allows us to implement a BEC interferometer on an atom chip. G.-B. Jo et al., Phys. Rev. A, 74, 013611-1-13, (2006)

D1.00120 Enabling Chip-Based Atom Interferometer II: Working with Atom-Atom Interactions and Phase Fluctuations in Dense, Elongated Gases, C.A. CHRISTENSEN, G.-B. JO, J.-H. CHOI, T.A. PASQUINI, Y.R. LEE, W. KETTERLE, D.E. PRITCHARD, MIT — BECs on atom chips tend to be dense and quite elongated. This leads to high mean-field interaction energy and phase fluctuations along the long dimension of the condensate. Interactions were expected to “heal” density imbalance and perturb coherent phase evolution, preventing reliable interferometry, while phase fluctuations across the sample may reduce signal-to-noise and imaging contrast. However, our experiments show that interactions promote long coherence time by number squeezing and enable in-situ phase readout by mapping the relative phase of separated BECs to the temperature of the system after merging. We also characterize phase fluctuations in our experiment, showing that they do not prevent reliable phase readout, but that they reveal an interesting regime of quasi 1-D degenerate gases.

D1.00121 Effects of Light Scattering and Collisions on a Single State Atom Interferometer, S. BEATTIE, I. CHAN, A. KUMARAKRISHNAN, York University — We have measured the effects of light scattering and collisions on the signal from a single state atom interferometer that uses laser cooled \(^{85}\)Rb. Two standing wave pulses separated by time \(T\) are used to diffract and rephase momentum states (corresponding to the \(F = 3\) ground state) in the vicinity of \(T = 2\T\). Light scattering and collisions reduce the timescale over which matter-wave interference can be observed. The decay rate of the signal is linearly proportional to the intensity of background standing wave light. The decay rate also scales inversely as the square of the detuning of the travelling components of the standing wave with respect to the \(F = 3 \rightarrow F = 4\) transition. These observations are consistent with the scattering rate associated with a standing wave potential. By varying the vapour pressure of the background \(^{85}\text{Rb}\) vapour, we show that the experiment is sensitive to velocity changes of \(\sim 100 \mu \text{m/s}\) and that the signal decay can be used to measure the cross section for hot-cold \(^{85}\text{Rb}\) collisions. By characterizing decoherence effects it is possible to extend the timescale of the experiment to the transit time limit and carry out a precision measurement of the atomic recoil frequency. We review the current status of this experiment.

D1.00122 Measurement of Gravitational Acceleration using a Single State Atom Interferometer, C. MOK, S. BEATTIE, I. CHAN, A. KUMARAKRISHNAN, York University — We review the development of a gravimeter using a single state atom interferometer. Two standing wave pulses separated by \(T\) are applied to a sample of laser cooled rubidium atoms. The first standing wave produces a density grating that is rephased by \(2\T\) by the second standing wave pulse. The rephased grating, known as an echo, is detected by coherently back scattering a traveling wave into a balanced heterodyne detector. The ratio of the in phase and quadrature components of the signal can be used to find the phase of the grating relative to an inertial reference frame. The accumulation of phase as a function of \(T\) can be used to find \(g\). Interestingly, the shape of the echo envelope contains temporal oscillations due to the Doppler shift, which can also be used to infer \(g\).

D1.00123 Quantum theory of atom lasers, TOBIAS KRAMER, Harvard University, MIRTA RODRIGUEZ PINILLA, ICFQ Barcelona — We present a three-dimensional, quantum mechanical and largely analytical theory for the properties of atomic laser beams in the gravitational field. The results describe both the total emission rate and the beam profile. Depending on the trapping frequencies and the strength of interactions, the theory predicts a transverse substructure in the atomic beam. Recent experiments on atom laser beam profiles are in good agreement with the model. References: T. Kramer and M. Rodriguez Quantum theory of an atom laser originating from a Bose-Einstein condensate or a Fermi gas in the presence of gravity Phys. Rev. A, 74, 013611-1-13, (2006)

D1.00124 Coherent Slowing of a Pulsed Supersonic Beam with an Atomic Paddle, ADAM LIBSON, EDVARDAS NAREVICIUS, MAX RIEDEL, CHRISTIAN PARTHEY, ISAAC CHAVEZ, Center for Nonlinear Dynamics and Department of Physics, The University of Texas at Austin, Austin, Texas 78712-1081, USA, UZI EVEN, Sackler School of Chemistry, Tel-Aviv University, Tel-Aviv, Israel, MARK RAIZEN, Center for Nonlinear Dynamics and Department of Physics, The University of Texas at Austin, Austin, Texas 78712-1081, USA — We report the slowing of a supersonic beam by elastic reflection from a receding atomic mirror. Supersonic beams, formed by the adiabatic expansion of high pressure gas through an aperture, are currently the highest brightness sources available and have a high degree of monochromaticity. We use a pulsed supersonic nozzle to generate a \(511 \pm 9\) m/s beam of helium that we slow by reflection from a Si(111)-H(1x1) crystal placed on the tip of a spinning rotor. We are able to continuously reduce the velocity of the beam by \(1\) mm/s and show that the temperature of the slowed beam is lower than 250 mK in the co-moving frame. We plan to use this beam as a probe for surface science studies and as the source for atom optics and interferometry experiments. The slow, cold, and intense nature of the beam should open new energy ranges and resolutions, allowing higher precision measurements.
D1.00125 Controlling atomic motion in optical billiards  J. LÉPINE, G. PAINCHAUD-APRIL, J. POIRIER, Université Laval, L. J. DUBÉ, Uni. Laval - Uni. Pierre et Marie Curie — We present different scenarios to control atomic motion in optical billiards [1] under conditions where classical chaos is present. Since the billiard boundary is drawn with appropriately deflected beams of light, giving rise to an effective static potential barrier, the motion of the enclosed atoms can be influenced by judiciously chosen small dynamical deviations of the scanning beams. We in fact demonstrate, by realistic numerical simulations, that the, otherwise chaotic behaviour, can be controlled and made stable and predictable. By selecting different cavity shapes (stadium, multipolar deformations of the circle, (smoothed) polygons etc.), we study our stabilization approaches under conditions ranging from mixed to fully chaotic dynamics and analyse the effects of soft boundaries and imperfections on the robustness of the control techniques. This acquired controlled ability offers a new tool for testing fundamental questions at the border of classical and quantum chaos.


D1.00126 CONDENSED MATTER PHYSICS —

D1.00127 Photoconductivity of Yttrium Praseodymium Gadolinium Oxalate Crystals  SOOSY KURYAN, ROSALIN ABRAHAM, Research Scholar, JAYAKUMARI ISAC, Guide, SOOSY KURYAN TEAM — Crystals are pillars of modern technology. Yttrium Praseodymium Gadolinium oxalate (YPGaOx) crystals were grown by gel method by the diffusion of Yttrium Chloride, Praseodymium Chloride, and Gadolinium Chloride into the set gel containing Oxalic acid. Silica gel method is capable of yielding crystals of high optical perfection and wide morphology. The growing crystals are held in the gel medium in a strain free manner and at the same time nucleation and super saturation are well controlled. Photo conductivity studies of these crystals revealed negative photoconductivity nature. The photocurrent is found to be less than the dark current at every applied electric field. Rare Earth compounds are known for their interesting electric, magnetic and luminescent properties. Recent investigations on the fluorescence of some rare earth oxalates suggest their potentiality for their optical applications. Rare Earth oxalates evoked greater attention because of their ionic conduction.

D1.00128 ABSTRACT WITHDRAWN —

D1.00129 Optical properties of vanadium doped ZnTe thin cermet films  KHAIRUL ALAM KHAN, M. SAZZAD HOSSAIN, M. REZAUL ISLAM, Dept. of App. Phys. & Electronic Engg., University of Rajshahi, Rajshahi-6205 — ZnTe:V thin cermet films (containing 0 to 10wt% V in ZnTe matrix) were prepared onto glass substrate by e-beam evaporation in vacuum at ~0.0001 Pa. The deposition rate of the films was about 2.05 nm/s. The effects of various deposition conditions on the electrical and optical properties of the cermet films have been studied in detail. The structure analysis of the film was performed by X-ray diffraction technique and it was found that the films are amorphous in nature. The optical properties of both the as-deposited and annealed films were studied in the wavelength range 300 < \( \lambda \) < 2500 nm, respectively. For both types of cermet sample, the values of Urbach tail, optical band gap, refractive index and dielectric constants were evaluated for different compositions and thicknesses, respectively. Evaluation of these parameters may help in view of their technological applications in selective surface as well as in optoelectronic devices.

D1.00130 Magnetic Field Noise from High Permeability Magnetic Shields for Precision Measurements S.-K. LEE, S.J. SMULLIN, T.W. KORNACK, M.V. ROMALIS, Princeton University — High permeability magnetic shields often generate magnetic field noise that can limit the sensitivity of precision measurements. We show that calculations based on the fluctuation-dissipation theorem allow evaluation of magnetic field noise, either by current or spin fluctuations, from high permeability metals and ferrites over a broad frequency range. For example, the noise spectrum of a mu-metal shield generally exhibits three distinct frequency dependent behaviors: low frequency 1/f spin noise, white noise due to Johnson noise current, and high frequency roll-off due to self-shielding. To reduce the effect of Johnson noise current, we built a multi-layer shield for a potassium SERF atomic magnetometer using ferrite for the innermost layer. We found that the white noise was reduced from about 20 \( fT/Hz \) to 0.75 \( fT/Hz \), as expected for an all-mu metal shield, to 0.75 \( fT/Hz \), limited by laser noise. The low frequency 1/f noise agreed well with calculation based on the measured complex permeability of the ferrite. Our method can be used to identify low noise shielding materials for further suppression of shield-generated noise for compact atomic magnetometers.

Wednesday, June 6, 2007 6:00PM - 7:48PM —
Session E1 Nobel Symposium TELUS Convention Centre Macleod BC

6:00PM E1.00001 TBD, TED HÄNSCH, Ludwig-Maximilians-Universität —

6:36PM E1.00002 Emission, Absorption and Scattering of Light by a Group of Atoms, ROY GLAUBER, Harvard University — Identical atoms that are not too far apart freely exchange their excitations. That phenomenon leads to a number of interesting behaviors characteristic of these elementary processes involving radiation.

7:12PM E1.00003 TBD, JOHN HALL, NIST/JILA —

Thursday, June 7, 2007 8:00AM - 10:24AM —
Session G1 Optical Lattices TELUS Convention Centre Macleod BC

8:00AM G1.00001 Cold atoms and the 2D Bose-Hubbard model, IAN SPIELMAN, NIST — Cold atoms in optical lattices provide new avenues for studying iconic condensed matter problems. Using an initially Bose condensed sample of \(^{87}\)Rb atoms, we implement the 2D Bose-Hubbard model (one intense lattice beam partitions the system into an ensemble of 2D systems; the remaining 2D lattice potential determines the constants in the Bose-Hubbard model). This model has a superfluid-insulator transition, and this work focuses on the insulating phase. We carefully control the lattice lattice parameters, the loading procedure, and the total atom number and we measure momentum distributions which agree quantitatively with the predictions of theory (for a homogenous system). In our images, we also measure correlations in the atom-shot noise which given information regarding the spatial extend of the system. The correlation signal changes as expected as the insulating region develops.
for the generation, characterization, and detection of N00N and related entangled states of light. For the implementation of quantum information processing protocols implies potential breakthroughs in other sciences and technologies. We discuss recent advances in quantum mechanics enables large enhancements in computational efficiency and communication security. Naturally, precise control of quantum systems required.

N00N States?


9:12AM G1.00003 Atomic and molecular quantum gases in an optical lattice. JOHANNES HECKER DENSCHLAG, Institut fuer Experimentalphysik, Universitaet Innsbruck — We report on recent progress in preparing and manipulating ultracold atomic and molecular ensembles in a 3D optical lattice. Starting from an atomic $^{87}$Rb condensate which is adiabatically loaded into a 3D optical lattice we can control the state and dynamics of the gas on the quantum level with the help of static magnetic fields, radio-frequency and laser radiation and a Feshbach resonance. For example, we can produce a pure molecular ensemble of $^8$He molecules in the lattice [1] and can coherently transfer it to a more densely molecular bound state via STIRAP [2] or radio-frequency transitions. Besides possible applications for investigating molecular collisions and producing ultracold molecules in the vibrational ground state, this can also be used for spectroscopic precision measurements of molecular levels. Besides studying chemically bound molecules, optical lattices also allow for forming a novel kind of stable bound state of two atoms which is based on repulsion rather than attraction between the particles [3]. We will explain how these lattice-induced repulsively bound atom pairs come about and discuss their interesting properties.


9:48AM G1.00004 Evidence for superfluidity of ultracold fermions in an optical lattice. JIT KEE CHIN, Massachusetts Institute of Technology — Ultracold fermions in periodic potentials hold promise for studies of quantum order in crystalline materials, since the observables and the parameter regime accessed differ greatly from traditional condensed-matter systems. Condensation of fermion pairs is an example of macroscopic phase ordering, and is a first step towards the realization of more exotic orderings. Starting with a pure superfluid of $^6$Li pairs in the BEC-BCS crossover, we adiabatically ramp up an optical lattice potential and allow the system to equilibrate. Upon release, the atom cloud expands and self-interferes, revealing the phase-relation across the different lattice sites. The appearance of sharp momentum peaks corresponding to momenta $2\pi \ell/\ell$ carried by $^6$Li pairs of mass $2m_3$ implies long-range phase coherence in the system. Such observations have traditionally been taken as an experimental indicator of superfluidity in an optical lattice, where the transport of atoms occurs by quantum mechanical tunneling and not by simple propagation. The effect of deep lattice depths and the role of interactions on the phase ordering and detection across the entire crossover are also explored.


Thursday, June 7, 2007 8:00AM - 10:24AM —
Session G2 Quantum Metrology and Imaging —
TELUS Convention Centre Macleod D

8:00AM G2.00001 Multi-Photon Quantum Interferometry. DIRK BOUWMEESTER, Department of Physics, University of California Santa Barbara — Based on the investigation of multi-photon entanglement, as produced by stimulated parametric down-conversion, a technique is presented to create heralded "noon" states. The relevance for interferometry will be discussed. Furthermore we explored the use of photon-number resolving detectors in Mach-Zehnder type of interferometers. Our current detectors can distinguish 0, 1, 2, to7, photon impacts. Although the overall collection and detection efficiency of photons is well below unity (about 0.3) the photon number resolving property is still very useful if combined with coherent input states since those state are eigenstates of the photon annihilation operator. First we analyze the coherent state interferometer with a single photon-number resolving detector, revealing the phase-relation across the different lattice sites. The appearance of sharp momentum peaks corresponding to momenta $2\pi \ell/\ell$ carried by $^6$Li pairs of mass $2m_3$ implies long-range phase coherence in the system. Such observations have traditionally been taken as an experimental indicator of superfluidity in an optical lattice, where the transport of atoms occurs by quantum mechanical tunneling and not by simple propagation. The effect of deep lattice depths and the role of interactions on the phase ordering and detection across the entire crossover are also explored.


8:36AM G2.00002 Quantum Imaging: Enhanced Image Formation Using Quantum States of Light. ROBERT W. BOYD, University of Rochester — Image formation based on the use of quantum states of light permits significant new possibilities in the field of image science. In this contribution, we review some of the conceptual possibilities afforded by quantum imaging, and we describe recent work that displays some of these features. The underlying idea of quantum imaging is to implement ideas and techniques from the fields of quantum optics and quantum information science to perform image formation with sensitivity and resolution exceeding that available using classical techniques. Examples of improved image formation includes techniques to form images with resolution exceeding the traditional Rayleigh limit and techniques based on entangled photons to allow the formation of images using photons that have never interacted with the object to be imaged. Quantum imaging systems can also be used to detect weak phase and amplitude objects in the presence of background noise with a sensitivity that exceeds the classical shot-noise limit. Possible long term implications of quantum imaging include its implementation in systems for quantum computing and quantum teleportation, thereby greatly increasing the information capacity by exploiting the parallelism intrinsic to image-bearing optical beams.

9:12AM G2.00003 Optical Quantum Imaging, Computing, and Metrology: What’s New With N00N States? . JONATHAN DOWLING, Louisiana State University — Information science is entering into a new era in which certain subtleties of quantum mechanics enables large enhancements in computational efficiency and communication security. Naturally, precise control of quantum systems required for the implementation of quantum information processing protocols implies potential breakthroughs in other sciences and technologies. We discuss recent developments in quantum control in optical systems and their applications in metrology and imaging. In this context, we particularly focus on novel schemes for the generation, characterization, and detection of N00N and related entangled states of light.
9:48AM G2.00004 Mode-mashing and quantum interferometry with triphoton states, AEPHRAIM STEINBERG, CQIQC & Physics, University of Toronto — For a number of years, many proposals have observed that the resolution of interferometry could be vastly improved, reaching the “Heisenberg limit” of $\Delta \phi \approx 1/N$, if the particles in the interferometer could be in a maximally entangled state of all travelling one path or the other, $|N\rangle > |0,0\rangle$, or “NOON.” This is a quadratic improvement over the shot-noise limit in classical interferometers, and might lead to significant improvements in metrology, and possibly even lithography. Unfortunately, given the nearly non-interacting nature of photons, such states have proved elusive for $N > 3$. Recently, a new theoretical approach based on post-selective nonlinearity has paved the way to scalable generation of such states, which we have generated for $N = 3$. In this talk, I review this approach, our experiment based on what we term “mode-mashing,” and their future prospects and limitations. I also discuss the difficult issue of how to perform complete quantum characterisations of such multi-photon states, in which the particles are distinguished only by their polarizations, which are in a complicated entangled state. We have generalized the standard techniques of quantum tomography to take into account the potential presence of extra “distinguishing” information inaccessible to measurement, and discuss the resulting limitations on one’s ability to fully describe a quantum state. In the limit of completely indistinguishable photons, we argue that the N-photon object should be thought of essentially as a single composite spin-N/2 particle, whose polarisation state may be described by a generalized Wigner quasiprobability distribution over the classical phase space which is the surface of the Poincaré sphere. We generate a variety of coherent, spin-squeezed, and maximally entangled states, and show the resulting Wigner functions and density matrices.

References

Thursday, June 7, 2007 8:00AM - 10:24AM
Session G3 Attosecond Science: The Next Frontier

8:00AM G3.00001 Probing proton dynamics in molecules on an attosecond timescale, SARAH BAKER, Imperial College London — A new technique for probing the ultrafast structural rearrangements of light molecules following ionization was demonstrated by our group earlier this year. This technique, termed PACER (probing attosecond dynamics by chrip encoded recollision), interrogates the motion of intramolecular nuclei following ionization via the process of high-harmonic generation (HHG). The strength of harmonic emission on return of the continuum electron wavepacket is weaker the more nuclear motion has occurred in the short time window since ionization. Moreover, since different harmonic orders are emitted at different times, dynamical information is gained by simply recording an harmonic spectrum and examining the change in signal as a function of order (which maps directly to time). Previously the nuclear dynamics of $H_2^+$ and $D_2^+$ were reliably determined at a temporal resolution limited by the difference in emission time of successive harmonic orders (roughly 100 as). The time window accessed in the measurement was 0.9 – 1.5 fs following ionization. Enlargement of this time window would be a valuable extension to the PACER technique. To this end, we have now performed a PACER measurement in $H_2$ and $D_2$ at longer pump wavelengths (increasing the average electron return time). This work was conducted at the Advanced Laser Light Source facility, using a HE-TOPAS system producing 110 fs pulses in the mid-IR. We observed multiple harmonic orders at pump wavelengths of 1300 nm and 1450 nm using on-target intensities of < 1 x 10^{14} Wcm^{-2}. Data at the two pump wavelengths was found to be in qualitative agreement with the known nuclear dynamics of the $H_2^+$ and $D_2^+$ ions to 2 ns after ionisation. Extension of the time window accessed by the PACER measurement is therefore promising, however, at the pulse durations employed we expect partial alignment of the molecules during the pulse, and therefore the effect of two-centre interference must be carefully examined.

8:36AM G3.00002 Coulomb and polarization effects in dynamic imaging with strong laser fields, OLGA SMIRNOVA, SIMS NRC — Interaction of few-cycle intense infrared laser pulses and attosecond XUV pulses with atoms and molecules opens new avenues for imaging electronic dynamics and molecular structures with sub-Angstrom spatial and sub-femtosecond temporal resolution. These approaches are based on either (i) photo-ionization by an attosecond pulse in the presence of a strong IR field or (ii) on laser-field driven electron recollision with its parent molecule following strong-field ionization of the molecule. Information about electronic dynamics and molecular structures can be recorded either in photoelectron spectra or in the high-frequency radiation emitted during electron recollision with the parent ion. The combination of high temporal and spatial resolution does not come for free. In all approaches, strong laser field is present during the interaction, affecting dynamics of both bound and continuum electrons in a complex way. Quantitative analysis of strong-field approaches requires understanding of both laser-induced polarization effects (bound dynamics) and interplay of ionic potential and strong laser field in the electron motion in the continuum. In this talk I will describe theoretical approaches to analyzing these effects and their use in mapping the electronic localization and high-frequency emission spectra. In particular, I will describe how electron localization affects spectra of high-frequency emission and how attosecond dynamics of laser-induced polarization can be visualized in photo-electron spectra. Finally, I will analyze scattering phase-shifts and modifications in the photo-electron spectra due to the interplay of the Coulomb field of the parent ion and the strong laser field. This analysis provides foundation and limitations for simple recipes of reconstructing molecular structures in strong-field approaches.

9:12AM G3.00003 Two-electron atomic response on the attosecond time-scale, KENNETH TAYLOR, DAMTP, The Queen’s University of Belfast — Over the past decade or so we have developed methods [1] that now allow accurate two-electron solutions of the full-dimensionality Time-dependent Schroedinger equation to be constructed and temporally followed as they evolve on the attosecond time-scale. A survey of the achievements of this work will be presented. These range from the prediction of Double Above Threshold Ionisation [2] brought about by intense light in the EUV, through the prediction of uni-lateral double ionization by longer wavelength light [3] to the prediction of a surprising energy-partition between the two electrons ionizing as a result of a recollision process at Ti:sapphire wavelengths [4]. The talk will go on to describe new theoretical investigations pertinent to the imminently-available XFEL sources and also to FEL and IR lasers in combination.

References

9:48AM G3.00004 Generation and control of attosecond pulses, ERIC CONSTANT, CELIA, Université Bordeaux 1, CEA, CNRS, 351 Cours de la libération 33 4 05 Talence France — Generating attosecond (1 as = 10^{-18} s) pulses both as trains of pulses or as isolated sub-femtosecond pulses is now possible with high order harmonic generation combined with temporal confinement techniques. As this source gets available, diverse applications of these pulses are emerging. To fulfill the requirements imposed by these applications (tunability, bandwidth, pulse duration and so on), the attosecond pulses have to be controlled. In this talk I will present how manipulating the polarization of an intense short pulse allows us to generate isolated attosecond pulses (or short burst of attosecond pulses) and what are the required characteristics for the fundamental pulse. I will describe the opportunities offered by this polarization gating approach in terms of control of the attosecond pulses, especially for their tunability, duration and bandwidth of the attosecond pulse or pulse train. Using these pulses for performing time resolved experiment with attosecond accuracy is also a challenge and I will present some tools that we developed for high resolution pump-probe experiments like for instance a simple ultra-stable interferometer that offers a temporal resolution of few as.
**8:00AM G4.00001 Phase Diagram of a Polarized Fermi Gas Across a Feshbach Resonance**

WENHUI LI, YEAN-AN LIAO, GUTHRIE PARTRIDGE, RANDY HULET, Department of Physics and Astronomy and Rice Quantum Institute, Rice University, Houston TX, 77251 — We investigate a Fermi gas of $^6$Li atoms with unbalanced populations in two spin states, whose interactions are tuned by a Feshbach resonance. At the unitarity limit, we observe three distinct phases connected by a tricritical point on a polarizability vs. temperature ($P-T$) phase diagram: a phase-separated state at low $T$, a polarized superfluid and a polarized normal gas at higher $T$. We are currently mapping out the phase diagram as a function of $P$, $T$ and interaction. At $T = 0$, as the interaction strength is tuned toward the BEC side of the resonance, we expect to encounter a phase boundary between the phase-separated state and the polarized superfluid. Conversely, on the BCS side, for finite $P$, a transition to the polarized normal gas is expected. We will present our latest results.

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**8:12AM G4.00002 Spatially resolved RF spectroscopy of a strongly interacting trapped Fermi gas**

YONG-IL SHIN, CHRISTIAN SCHUNCK, ANDRE SCHIROTZEK, WOLFGANG KETTERLE, MIT — RF spectroscopy has been used to study unitary limited interactions and pairing in a strongly interacting Fermi mixture. However, most of the spectroscopy experiments have been performed with inhomogeneous samples confined in trapping potentials, eventually limited by the density broadening effects. We developed spatially resolved RF spectroscopy based on the in situ imaging of the trapped samples. We obtained a density-broadening-free RF spectrum and clearly identified a gap in the RF spectrum of strongly interacting Fermi mixtures. In this talk, we will present a measurement of the pairing gap energy of a Fermi mixture at the unitarity limit.

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**8:24AM G4.00003 Scissors mode oscillations for a finite-temperature strongly-interacting ultracold Fermi gas**

M. J. WRIGHT, S. RIEDEL, A. ALTMAYER, C. KOHSTALL, E. SANCHEZ, J. HECKER DENSCHLAG, R. GRIMM, Inst. of Experimental Physics and Center for Quantum Physics, Univ. Innsbruck; 6020 Innsbruck, Austria — We investigate the finite-temperature phase diagram for a strongly-interacting Fermi gas. This system consists of two distinct regimes, hydrodynamic and collisionless, which have different collisional properties and depend on interaction strength and temperature. We study the transition from hydrodynamic to collisionless behavior throughout the crossover by examining the scissors mode. This mode proves to be an excellent candidate for finite-temperature measurements as the oscillation is independent of the equation of state and has a low damping term, which provides better resolution of the mode’s frequency characteristics.

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**8:36AM G4.00004 Paired Phases of a Trapped Fermi Gas with Unequal Spin Populations**

G.B. PARTRIDGE, WENHUI LI, Y.A. LIAO, R.G. HULET, Department of Physics and Astronomy and Rice Quantum Institute, Rice University, Houston TX, 77251 — A strongly interacting ultra-cold gas of fermionic $^6$Li with unequal numbers of two spin components exhibits two distinct low temperature states. Phase separation is observed at the lowest temperatures, where a uniformly paired core is maintained in the center of the trap, up to large number imbalance, by the expulsion of excess unpaired atoms. Sharp boundaries between the core and the unpaired atoms are consistent with a first-order phase transition. In addition, the spatial distribution of the superfluid core deforms, in violation of the local density approximation. At higher temperature, the core remains unpaired up to a critical polarization before going normal, but does not deform. The boundaries are not sharp in this case, indicating a partially polarized shell between the core and the unpaired atoms. The temperature dependence is consistent with a tri-critical point in the phase diagram.

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**8:48AM G4.00005 Photoassociation Rate of a $^7$Li Bose-Einstein Condensate near a Feshbach Resonance**

M. JUNKER, D. DRIES, Y.P. CHEN, C. WELFORD, J. HITCHCOCK, R.G. HULET, Department of Physics and Astronomy and Rice Quantum Institute, Rice University, Houston, TX 77005 — In a photoassociation (PA) process a pair of atoms collide in the presence of a resonant light field creating an excited molecule. For ultracold atoms, the rate of PA depends on the $s$-wave scattering length, $a_s$, which determines the wavefunction overlap between the collisional ground state and the excited molecular bound state. We investigate this dependence experimentally using a pure Bose condensate of $^7$Li in the $F=1$, $m_F=1$ hyperfine state confined in an optical dipole trap. We vary $a_s$ below the 730 G Feshbach resonance and measure the rate of loss from the condensate due to a PA pulse which couples atoms to the $\Sigma^+_g$ vibrational level of the $^1\Sigma^+_g$ molecule state. The measured loss rate varies by more than a factor of 30 over the magnetic field range of 660 - 730 G. At 710 G the rate approaches zero, which we attribute to a node in the ground state wavefunction.

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**9:00AM G4.00006 Bragg spectroscopy of a strongly interacting BEC**

S.B. PAPP, J.M. PINO II, R.J. WILD, D.S. JIN, C.E. WIEMAN, E.A. CORNELL, JILA: NIST and the University of Colorado — The ability to tune the scattering length in ultracold atomic gases has enabled access to strongly interacting Bose-Einstein condensates (BECs). Particularly intriguing physics is expected to occur when the scattering length is increased to on order of the interatomic spacing; in this case many-body interactions are important. The capability to probe the excitation spectrum of the BEC will be important in understanding this experimental regime. We will report initial Bragg spectra of a strongly interacting BEC. Using a Feshbach resonance, we vary the scattering length in a $^{87}$Rb BEC to study the Bragg spectra over a wide range of interaction strength.

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**9:12AM G4.00007 A Simple Mean-Field Model of Steady-State Magnetoassociation of an Atomic BEC in a Feshbach Resonance**

ANDREW CARMICHAEL, JUHA JAVANAINEN, University of Connecticut — We investigate a simple mean-field model describing magnetoassociation of a single species atomic Bose-Einstein condensate in the presence of a Feshbach resonance. The Hamiltonian, which allows for the creation and destruction of Bose-condensed molecules, leads to Heisenberg equations of motion which are solved analytically in the steady state for the classical quantities of the occupancies of the atomic and molecular condensates and the anomalous pairing amplitudes. Approximations include the elimination of non-condensed molecules.

PASCAL NAIDON, EITE TIESINGA, National Institute of Standards and Technology, FRANCOISE MASNOU-SEEUWS, Laboratoire Aimé Cotton, PAUL JULIENNE, National Institute of Standards and Technology — Photoassociation is a process by which two colliding atoms associate into an excited bound state by absorbing a resonant photon. This excited state subsequently decays by spontaneous emission. The atom loss rate in a gas photoassociated by a laser can be calculated from the two-body theory. It is linear with the laser intensity for small intensities, then saturates and decreases at higher intensities, in accordance with the two-body unitary limit. Many-body models have predicted that the rate of photoassociation in a Bose-Einstein condensate may saturate before the unitary limit. However this rate limit has not been observed. We revisit the many-body theory of photoassociation in a condensate and explain why the rate limit has not been seen. In particular we identify two different regimes, the coherent and the adiabatic regimes. All photoassociation experiments up to now have been performed in the adiabatic regime, for which the limitation on the rate occurs at larger intensities than initially predicted by many-body models. We also find that this limitation on the rate is essentially a two-body effect rather than a many-body effect. Finally we investigate the possibility to explore the coherent regime using Bose-Einstein condensate of alkaline-earth metals.

9:36AM G4.00009 Rogue decoherence in the formation of a macroscopic atom-molecule superposition .

MATT MACKIE. Temple University, OLAVI DANNENBERG, Helsinki Institute of Physics — We theoretically examine two-color photoassociation of a Bose-Einstein condensate, focusing on the role of rogue decoherence in the formation of macroscopic atom-molecule superpositions. Rogue decoherence occurs when two zero-momentum condensate atoms are photoassociated into a molecule, which then dissociates into a pair of atoms of equal-and-opposite momentum, instead of dissociating back to the zero-momentum condensate. As a source of decoherence that may damp quantum correlations in the condensate, rogue dissociation is an obstacle to the formation of a macroscopic atom-molecule superposition. We study rogue decoherence in a setup which, without decoherence, would yield a macroscopic atom-molecule superposition, and find that the most favorable conditions for said superpositions are a density \( p \sim 10^{12} \text{ cm}^{-3} \) and temperature \( T \sim 0.1 \text{ nK} \).


CHENG CHIN, James Franck institute and Physics Department, University of Chicago, VICTOR FLAMBAUM, University of New South Wales — Scattering length, which can be measured in Bose-Einstein condensate and Feshbach molecule experiments, is extremely sensitive to the variation of fundamental constants, in particular, the electron-to-proton mass ratio \( (m_e/m_p) \), where \( m_e \) is the electron mass. Based on single- and two-channel scattering models, we show how the variation of the mass ratio propagates to the scattering length. We suggest that variation of \( m_e/m_p \) on the level of \( 10^{-11} \sim 10^{-14} \) can be detected near a narrow Feshbach resonance by monitoring the scattering length on the 1% level. In this talk, we will present evidence that demonstrates the ultrahigh sensitivity on atomic mass and suggest possible experiment approaches to precisely determine the scattering lengths.

10:00AM G4.00011 Nonequilibrium free-fermion pair correlations in molecular dissociation.

KAREN KHERUNTSYAN, MATTHEW DAVIS, MURRAY OLSEN, University of Queensland, ARC Centre of Excellence for Quantum-Atom Optics — We analyze the pair correlations of fermionic atoms formed through the dissociation of a Bose-Einstein condensate of molecular dimers. With bosonic atomic constituents, this would be a direct atom optics analog of optical parametric down-conversion. Known as the best source of squeezed light and entangled photon pairs, down-conversion has led to a number important applications, such as precision measurements and fundamental tests of quantum theory. We envisage that molecular dissociation will play a similarly important role in quantum-atom optics in the near future, with the different possible quantum statistics of the constituent atoms revealing new physics. Here we discuss how the fermionic statistics leads to the new paradigm of fermionic quantum-atom optics. Using a simple theoretical model for molecular dissociation, we analyze the pair correlations between the fermionic atoms in two spin states and quantify the strength of correlations via number-difference squeezing [1]. This is the first step towards a quantitative theoretical analysis of recent experimental measurements of atom correlations in dissociation of potassium dimers performed at JILA [2]. [1] K.V. Kheruntsyan, Phys. Rev. Lett. 96, 110401 (2006). [2] M. Greiner et al., Phys. Rev. Lett. 94, 110401 (2005).

10:12AM G4.00012 Equation of state of Bose and Fermi systems beyond s-wave determined by the lowest order constrained variational method: large scattering length limit.

RYAN KALAS, Washington State University, DOERTE BLUME, Washington State University, and JILA, University of Colorado — Dilute Fermi systems with large s-wave scattering length \( a_s \) exhibit universal properties if the interparticle spacing \( r_0 \) greatly exceeds the range of the underlying two-body interaction potential. In this regime, \( r_0 \) is the only relevant length scale and observables such as the energy per particle depend only on \( r_0 \) (or, equivalently, the energy \( E_{FG} \) of the free Fermi gas). We investigate Bose and Fermi systems with non-vanishing angular momentum using the lowest order constrained variational (LOCV) method. We focus on the regime where the generalized scattering length becomes large and determine the relevant length scales at unitarity. We obtain simple expressions for the energy per particle in terms of a combined l-dependent length scale \( \xi_l \). For example, within the LOCV framework the energy per particle of p-wave and d-wave interacting fermions depends not only on \( E_{FG} \), as in the case of s-wave fermions, but also on an energy scale that depends on the range of the underlying two-body potential. Furthermore, we investigate the behaviors of s-wave interacting Bose and Fermi systems in the non-universal, density-dependent regime.

Thursday, June 7, 2007 8:00AM - 10:12AM –
Session G5 Clocks & Tests of Fundamental Symmetries TELUS Convention Centre Glen 205

8:00AM G5.00001 Optical Clock with Fermionic Strontium.

S. BLATT, M.M. BOYD, A.D. LUDLOW, T. ZELEVINSKY, S.M. FOREMAN, T. ZANON, G.K. CAMPBELL, J. YE, JILA, National Institute of Standards and Technology and the University of Colorado, Department of Physics, University of Colorado, Boulder, CO, 80309 — We present recent results from our optical atomic clock based on neutral \(^{87}\text{Sr}\) in an optical lattice. By probing the \(^{155}\text{Xe} - ^{133}\text{Cs}\) clock transition with a sub-Hz linewidth diode laser, we recover spectra with quality factors \( Q \geq 2 \times 10^{14} \). The clock frequency was measured as \( 429.228.004.229.874.0(1.1) \text{ Hz} \), with systematic uncertainty \( < 9 \times 10^{-16} \), a level of performance approaching current Cs fountains. Stability is currently limited by the Cs-fountain-calibrated hydrogen maser used as the frequency standard. The measured frequency agrees well with our previous data as well as recent measurements by the Paris and Tokyo groups. Work toward direct comparison of optical frequency standards is in progress.
8:12AM G5.00002 Progress toward an Yb Optical Lattice Clock, ZEB BARBER, NIST-Boulder/Univ. of Colorado, JASON STALNAKER, CHRIS OATES, LEO HOLLBERG, NIST-Boulder — Optical atomic clocks based on the $^1\text{S}_0-^3\text{P}_0$ transition in neutral Sr or Yb atoms confined to optical lattices are rapidly gathering momentum. Three different labs have published frequency measurements of Sr based standards that agree to 1 part in $10^{14}$, and several clocks based on Yb are being built around the world. We present recent progress at NIST on an Yb optical clock. This clock utilizes a moderate ($\sim 1 \text{ mT}$) external magnetic field to (weakly) allow the clock transition at 578 nm in an even isotope of Yb. We have observed very narrow ($\sim 4 \text{ Hz}$) spectroscopic lines, measured the Stark-free lattice wavelength (759.3555/0.001 nm), and have made comparisons against other optical frequency standards. In addition, we present investigations on the effect of lattice polarization on clock frequency shifts. We also describe the development a new laser source for the clock transition. This solid state laser system uses sum frequency generation of a 1319 nm Nd:YAG and a 1030 nm fiber laser to generate the 578nm clock light.

8:24AM G5.00003 Novel scheme to stabilize compact atomic clocks, MICHAEL HOHENSEE, DAVID PHILLIPS, RONALD WALSWORTH, Harvard-Smithsonian — Compact atomic clocks such as CPT and N-resonance clocks are typically operated in regimes for which the resonant frequency of the clock is relatively insensitive to power and frequency fluctuations of the laser. We propose a novel scheme in which the atomic medium provides both a stable clock resonance, as well as resonances with high-sensitivity to laser fluctuations which can thus be used to control these technical variations.

8:36AM G5.00004 Testing relativistic time dilation with a two-velocity ion clock in a storage ring, G. GWINNER, University of Manitoba, Winnipeg, Canada, H. BUHR, S. REINHARDT, G. SAATHOFF, D. SCHWALM, A. WOLF, Max-Planck-Institute for Nuclear Physics, Heidelberg, Germany, G. HUBER, S. KARPUK, C. NOVOTNY, University of Mainz, Mainz, Germany, T.W. HANSCH, R. HOLZWARTH, T. UDEM, M. ZIMMERMANN, Max-Planck-Institute for Quantum Optics, Garching, Germany — We report on a new, improved test of time dilation in special relativity via the relativistic Doppler-effect. We use an optical transition with rest-frequency $\nu$ in $^7\text{Li}^+$ ions, stored at two different speeds of $\beta_1 = 0.064$ and $\beta_2 = 0.03$, respectively, in the TSR heavy-ion storage ring in Heidelberg. The Doppler-shifted excitation frequencies $\nu_1$ and $\nu_2$ for laser beams traveling parallel and antiparallel with respect to the ions are measured simultaneously using saturation spectroscopy in separate measurements at $\beta_1$ and $\beta_2$. The resonance conditions $\nu = \gamma(1 - \beta\nu)$ and $\nu = \gamma(1 + \beta\nu)$ yield the relation $\nu_1\nu_2 = \nu_2\nu_{2a}$, if $\gamma = 1/\sqrt{1 - \beta^2}$, as predicted by SR. Deviations, e.g. caused by the presence of preferred frames, are parametrized by $\gamma_{\text{SR}}(1 + \alpha\beta^2 + ...).$ We have established a preliminary new limit of $|\alpha| < 9 \times 10^{-8}$, a 25x improvement over non-storage-ring techniques. We will also review the progress towards a measurement at $\beta = 0.34$ at the GSI storage ring at Darmstadt, which will be key to reducing the limit on $\alpha$ even further.

8:48AM G5.00005 Nonlinear Pressure Shifts of $^{133}\text{Cs}$ Hyperfine Frequencies, FEI GONG, YUAN-YU JAU, WILLIAM HAPPER, Princeton University — The hyperfine (microwave) magnetic-resonance frequencies of optically pumped alkali-metal atoms in buffer-gas have long been used in compact, portable frequency standards. The buffer gas is needed to slow down the diffusion of optically pumped atoms to the cell walls, and to eliminate Doppler broadening of the microwave resonances. Van der Waals molecules, consisting of an alkali-metal atom loosely bound to a buffer gas atom, can form in such vapor cells. The molecules strongly affect the spin relaxation of alkali metal atoms in Ar, Kr and Xe gases at pressures of a few Torr. The hyperfine-shift interaction, $\delta\text{A-S}$, the modification a nearby buffer-gas atom makes to the Fermi contact interaction between $S$ and the nuclear spin $I$ of the alkali atom, can contribute to the width of the microwave resonance line, and it is responsible for the pressure shifts of the hyperfine resonance frequencies that are so important for clocks. Our experiments show that Van der Waals molecules also modify the effects of the hyperfine-shift interaction $\delta\text{A-S}$. For Ar pressures of a few tens of Torr or less, the shift of the microwave resonance frequency of $^{133}\text{Cs}$ in Ar buffer gas is not linear in the buffer gas pressure. This occurs because the contribution to the pressure shift from molecules is suppressed when $T \delta A > 1$.

9:00AM G5.00006 Precision Search for Lorentz and CPT-violating Interactions in the Electron Sector, CLAIRE CRAMER, University of Washington, BLAYNE HECKEL, ERIC ADELBERGER — We report recent results from an experimental search for Lorentz and CPT-violating forces coupling to spin-polarized electrons. We record the torque on a pendulum containing $10^{23}$ polarized electrons as a function of its angle with respect to large sources of spin-polarized electrons placed outside the torsion balance apparatus or with respect to a Lorentz-violating background field fixed in space. Our constraints on the background field are complementary to constraints in the proton and neutron sectors from maser and co-magnetometer experiments. Spin-spin results can be interpreted as constraints on axion-like pseudoscalar couplings, the exchange of low-mass bosons constrained only by rotational and translational invariance, and on forces mediated by the Nambu-Goldstone bosons that would arise in the context of spontaneously broken Lorentz symmetry. These Goldstone bosons, often referred to as the "ghost condensate" because they have a negative kinetic term in the Lagrangian stabilized by higher order terms, are particularly interesting because the energy scale accessible to our experiment is the scale on which they could contribute either to Dark Energy or Dark Matter. We will present preliminary results from the first experimental search for the unique signature of the ghost condensate's interaction with Standard Model fermions.

9:12AM G5.00007 Tests of Lorentz Symmetry with Gravitationally Coupled Atoms, JAY D. TASSON, V. ALAN KOSTELECKY, Indiana University — Violations of Lorentz symmetry provide a potential signal for new physics at the Planck scale. At presently accessible energies, these violations are described by the Standard-Model Extension (SME). In this talk I will outline the gravitationally coupled fermion sector of the SME and discuss a new sensitivity to Lorentz violation attainable in atom- interferometer experiments.

9:24AM G5.00008 Progress towards atomic magnetometry below room temperature, ALEXANDER SUSHKOV, DMITRY BUDKER, UC Berkeley — We are working towards obtaining ultra-narrow magneto-optical resonance lines with a vapor of paramagnetic atoms in a high-density buffer gas. Such ultra-narrow lines are used in a number of precision experiments and devices, such as an atomic magnetometer. Laser ablation of sub-millimeter diameter wires, as well as bulk targets, has been used to produce atomic vapor of a number of paramagnetic atoms: silver, gold, lithium, and rubidium. Vapor densities of $10^{11}$ cm$^{-3}$ are achieved in helium buffer gas (helium density on the order of $10^{18}$ cm$^{-3}$) at temperatures between 30 K and 295 K. Vapor lifetimes in excess of 100 ms are observed. The techniques of optical pumping and non-linear magneto-optical rotation can now be applied to these paramagnetic atoms at temperatures far lower than those needed to maintain an appreciable saturated vapor pressure necessary for vapor cell-based experiments.

9:36AM G5.00009 Progress toward improved symmetry tests with a dual noble gas maser, ALEX GLENDAY, MATTHEW ROSEN, DAVID PHILLIPS, RONALD WALSWORTH, Harvard-Smithsonian — Measurements of spin transitions in atomic systems can be sensitive to violations of Lorentz and CPT symmetry through Zeeman frequency variations as the direction or velocity of the system changes with respect to an inertial frame. We report improved performance of the $^{129}\text{Xe}/^{4}\text{He}$ Zeeman maser as a device for improved tests of such fundamental symmetries. Improved temperature and mechanical stability of the maser as well as signal optimization have led to an order of magnitude improvement in frequency noise and stability. Comagnetometry of the two noble gases also enables precision measurement of new forces that couple to the spin of the neutron.
9:48AM G5.00010 Rotating Co-Magnetometer for Tests of Fundamental Symmetries , S. J. SMULLIN, T.W. KORNACK, G. VASILAKIS, M.V. ROMALIS, Princeton University — Recent interest in tests of Lorentz and CPT symmetries have resulted in several new limits on spin coupling to a preferred direction in space. We are developing a rotating K-3He co-magnetometer to improve such limits. The co-magnetometer is based on a high sensitivity K magnetometer operating in spin-exchange relaxation free regime; in this case, the K is interacting with nuclear spin-polarized 3He buffer gas. When properly tuned, the coupling between the two atomic species makes the system insensitive to magnetic fields and sensitive to anomalous fields that indicate the presence of new physics. The compact co-magnetometer incorporates a number of novel features, such as a ferrite magnetic shield with much lower magnetic noise level than mu-metal and in-vacuum separation of all optical elements to reduce air convection noise and improve thermal stability. Periodic rotation of the apparatus allows much faster modulation of the expected signal. In this talk, I will discuss the performance of the apparatus and present initial results.

10:00AM G5.00011 ABSTRACT HAS BEEN MOVED TO P6.00010 --

Thursday, June 7, 2007 8:00AM - 10:00AM --
Session G6 Heavy Particle Collisions and Surface Interactions TELUS Convention Centre Olde Scotch Room

8:00AM G6.00001 ABSTRACT HAS BEEN MOVED TO P4.00013 --

8:12AM G6.00002 ABSTRACT HAS BEEN MOVED TO H4.00009 --

8:24AM G6.00003 Correlation between bound and continuous states of three identical particles 1, NICOLAS DOUGUET, VIATCHESLAV KOKOOULINE, Department of Physics of University of Central Florida — Study of degenerate cold gases represents today a wide field of physics, because phenomena in cold gases are relevant in several other fields of physics, like for instance, superconductivity or astrophysics. In this work, we discuss collisions of three identical particles in ultra-cold gases, by considering the symmetry of the total wave function of the system. Thus, we use either laboratory-frame, hyperspherical, or Jacobian coordinates, depending on which ones are best suited to describe the different configurations of the system. Precisely, for this purpose, we describe the wave function of the system at large distances, in order to understand the states of the particles before and after the three-body collision, but also consider the wave function at short distances during the actual collision process. Then, we are able to predict the possible quantum states of the particles after collision, by using symmetry considerations. In particular, we describe the recombination of the system into one free particle and a dimer. The result can be used for example, to identify possible decay products of quasi-stationary Efimov states.

1 Acknowledgment is made to the Donors of the American Chemical Society Petroleum Research Fund for support of this research.

8:36AM G6.00004 ABSTRACT HAS BEEN MOVED TO H4.00013 --

8:48AM G6.00005 A Novel Method to Analyze Four-Body Break-Up Processes , MICHAEL SCHULZ, University of Missouri-Rolla, DANIEL FISCHER, Stockholm University, THOMAS FERGER, ROBERT MOSSHAMMER, JOACHIM ULLRICH, MPI Heidelberg — Numerous kinematically complete experiments on a variety of atomic break-up processes have been performed in recent years. The fully differential cross sections (FDCS) extracted from such measurements provide the most sensitive tests of theory. However, one drawback of the FDCS is that they do not show a comprehensive physical picture of the process, but rather only for one specific kinematical setting at a time usually covering only a small fraction of the total cross section. Less differential data can be presented in conventional one- or two-dimensional plots without losing any part of the total cross section. However, for processes involving more than two particles these spectra are integrated over at least one fragment. Recently, we demonstrated that for single ionization (three bodies) Dalitz plots are a powerful tool to present data as a function of all three fragments simultaneously in a single spectrum without loss of any part of the total cross section 2. Here, we report on a generalization of Dalitz plots to four-body break-up processes. By using a tetrahedral coordinate system it has become possible for the first time to present measured data as a function of all four fragments simultaneously. 3 M. Schulz et al., J. Phys. B37, 4055 (2004)

9:00AM G6.00006 Acoustic Desorption from a Room Temperature Ionic Liquid. , PETER HARRIS, EUGENE TRACY, WILLIAM COOKE, College of William and Mary — We use laser induced acoustic pulses to efficiently desorb ions from a Room Temperature Ionic Liquid (RTIL) in vacuum. Our RTIL, 1-butyl-3-methylimidazolium hexafluorophosphate, remains a stable liquid at pressures exceeding 10^{-9} torr. We use the 2^{nd} harmonic of a Nd:YAG laser, 2ns pulse time, to generate acoustic pulses via laser ablation of the backside of a metal foil. Both negative and positive ions are desorbed from the liquid RTIL surface on the front side of the foil. The m/q of ejected ions is detected via TOF measurements from an imaging micro-channel plate detector. We measure the time our acoustic pulse reaches the RTIL surface by detecting the ejected electron signal. We present data showing the variation of desorbed ion yield as a function of the amplitude and shape of the incident acoustic pulse.

9:12AM G6.00007 Intermolecular separation dependence of dipole-dipole interactions between excited sodium atoms , BRIAN RICCONI, YAN XIAO, J. GARY EDEN, University of Illinois at Urbana Champaign — Wavepackets and parametric four-wave mixing (PFWM) was used to probe excited Na atoms with mean internuclear separations between 700 and 1100 Å. A pump-probe technique employing a nonlinear parametrically amplified oscillator to coherently probe the 4d and 5s energy states was used to observe the quantum beating at a frequency of 1348.1 cm^{-1}. Frequency analysis of the PFWM signal indicated the energy defect between the Na 5s-4d levels was perturbed and sidebands to the main frequency appeared. By monitoring the frequency difference between the perturbed and unperturbed oscillations, the sum of the interaction energies between one atom and all surrounding atoms may be obtained. Although two-body dipole-dipole interactions quantitatively account for the frequency spread, quantitative analysis shows that many-body interactions must be considered to be consistent with the observed splitting.

9:24AM G6.00008 Particle, Energy and Rovibrational Spectra of Molecules Chemically Sputtered of Carbon Surfaces 1, PREDrag KRSTIC, CARLOS REINHOLD, Oak Ridge National Laboratory, STEVEN STUART, Clemson University — We perform classical molecular dynamics simulations of the chemical sputtering of deuterated amorphous carbon surfaces by deuterium atoms and molecules at impact energies from threshold to 50 eV/D. Particular attention is paid to the preparation of the target surfaces for varying impact projectile fluence, energy and species [1]. The spectra of hydrocarbon molecules C_{x}D_{y}, with x in range 1 to 5 are observed, and spectral distributions of their translational, rotational and vibrational energies are analyzed. Angular spectra of the sputtered molecules are also analyzed. Our results show good agreement with existing experimental data. [1] P. S. Krstic, C. O. Reinhold, and S. J. Stuart, Europhysics Letters 77, 33002(2007).

1 We acknowledge support by the OFES (PSK) and the OBES (COR) of the U.S. DoE under contract No. DE-AC05-00OR22725 with UT-Battelle, LLC, and (SJS) of DoE (DE-FG02-01ER45889), the NSF (CHE-0239448) and a MURI managed by the ARO.
9:36AM G6.00009 Dielectric Spectroscopy Analysis of Aged EVOH films with Application to Deterioration of Food Packaging Materials, TIMOTHY HOELLER, DQR Testing Services. Samples of EVOH films from compositions of 29 - 44 mol% ethylene content were exposed to thermal aging with and without light exposure. The results of Dielectric Spectroscopy on select samples showed Cole-Cole plots of skewed dielectric constant indicating multiple distributions of dipole relaxation times. The onset for decreases in dielectric response occurs earlier in samples exposed to elevated temperature under light exposure. Lower permittivity is exhibited in samples of higher ethylene content. Results from heat exposed samples are presented. Colorimetric analysis indicates only a slight film yellowing in one case. Raman spectroscopy on untreated films discerns changes in the C-C-O stretch associated with the alcohol. The effects of aging on microstructure may cause hindrance of molecular motion from moisture desorption. Slight material degradation occurs from film hardening presumably due to crosslinking. An electrical circuit model of the conduction processes associated with the EVOH films is presented. Dielectric analysis shows promise for monitoring material changes related to deterioration. We are also using these methods to understand Fluorescence Imaging which has been recently released for paper and plastic materials analysis. Future work may include refinement of these techniques for identification of changes in material properties correlated to packaging material barrier resistance.

1Principle Investigator

9:48AM G6.00010 Application of Laser Induced Electron Impact Ionization to the SiH₄-NH₃ Hot Wire Chemical Vapor Deposition System, BRETT EUSTERGERLING, MARTIN HEDEN, YUJUN SHI, University of Calgary — The application of a laser induced electron ionization (LIEI) source in studying the gas phase chemistry of the SiH₄-NH₃ hot wire chemical vapor deposition system has been investigated. By directing an unfocused laser beam containing 118 and 355 nm radiation to the repeller plate in a Wiley-McLaren type time-of-flight mass spectrometer, photoelectrons were successfully liberated from the stainless steel plate. The large electric field in the ion optics region accelerated these photoelectrons, resulting in the ionization of species which are unavailable by the 118 nm single-photon ionization route (SPI, 10.5 eV). In all mixtures studied, it was found that any species with an ionization potential below 10.5 eV, e.g. Si₂H₆ and NH₃, were observed most strongly when pure SPI was used, whereas peaks corresponding to those species with IP's above 10.5 eV, e.g. H₂, N₂ and He, were strongest when LIEI was employed. Further investigations using a custom built, variable-energy photoelectron source will also be presented.

Thursday, June 7, 2007 10:30AM - 12:54PM — Session H1 Spectroscopy of Molecular Complexes, Clusters, and Aggregates TELUS Convention Centre Macleod BC

10:30AM H1.00001 Spectroscopy of molecular clusters in He droplets, ANDREY VILESOV, University of Southern California — Molecular spectroscopic experiments in He droplets will be reviewed. Results of the recent infrared laser study of ammonia and water clusters in He droplets will be presented. Hydrogen bonding in the studied clusters causes an enhancement of the intensity of the hydrogen stretching bands. Two types of the clusters show qualitatively different size dependence of the infrared intensity per hydrogen bond. In ammonia dimers and trimers it is close to the crystal value. In water clusters it increases monotonically with cluster size being in tetramers a factor of two smaller than in the ice. Thus larger water clusters are required in order to obtain the electronic distribution in clusters, which is characteristic for the bulk ice. Study of heterogeneous clusters such as containing water and HCl molecules will also be introduced. In the second part of the talk the utility of the helium droplet technique for growth and study of large atomic and molecular clusters of up to about 10⁴ particles is discussed. Size dependence of the spectra, allows studying the evolution of the system from single molecules to molecular solid and provides information on the structure of the large clusters formed in He droplets.

11:06AM H1.00002 Interplay between rotational dynamics, quantum solvation and superfluid response in doped helium clusters, NIKOLAY BLINOV, Department of Chemistry, University of Alberta — We show how state-of-the-art Quantum Monte Carlo methods assist in revealing the interplay between rotational dynamics, quantum solvation and superfluid response in doped helium clusters. While strong correlations exist between the size variation of the rotational constant and changes in structure, exchange effects are crucial to explain a non-monotonic evolution of the rotational constant of the complexes. We demonstrate that exchanges facilitate the decoupling between a dopant molecule and helium for cluster sizes where the effective anisotropy of the helium-dopant interaction is reduced due to structural changes. In addition, for the class of molecular dopants with a T-shaped He-molecule dimer configuration, the variations in the rotational constant can be unambiguously related to the non-trivial evolution of the helium superfluid response. This allows one to use a molecular dopant as an experimental probe of superfluidity at the microscopic level. We show that experimental superfluid response builds up in stages correlated with the filling of the solvation layers around the dopant molecule.

11:42AM H1.00003 Spectroscopy of Hydrogen clusters: Non-rigidity of large parahydrogen clusters at low temperatures, TAKAMASA MOMOSE, The University of British Columbia — Interest in quantum clusters has increased over the last decade. Especially, clusters of molecular hydrogen have been attracted attention because of the possible superfluid phase of hydrogen clusters. Here, we have studied hydrogen clusters (N=1 - 1000) embedded in superfluid He nano-droplets at 0.4 K. Laser induced fluorescence of Mg-phtalocyanine simultaneously doped in droplets showed clear evidence of non-rigidity of parahydrogen clusters at 0.4 K. We will discuss the difference of para and ortho hydrogen clusters as well as Ar clusters in He nano-droplets. Spectra in droplets (N=10⁵, T=4K) will also be discussed.
12:18PM H1.00004 Vibrational evidence for chiral recognition phenomena in vacuo\textsuperscript{1}, MARTIN A. SUHM, U. Goettingen — Molecules and molecular conformations which cannot be superimposed on their mirror image are chiral. Chirality or handedness plays an important role throughout the life sciences. When two molecules interact, they can sense their relative handedness, giving rise to spectroscopic signatures of chiral recognition. This is often mediated by hydrogen bonds, most versatile and directional intermolecular interactions. If the distinction between the homo- and heteroconfigurational pairs of molecules is large enough, chiral discrimination, i.e. differences in abundance may occur. The contact between two flexible, transiently chiral molecules may induce a matching of their handedness, i.e. chirality synchronization. Such phenomena are best studied at low temperatures in vacuum isolation, without perturbing interactions \textsuperscript{[1]}. Structural information on the isolated molecular complexes can be obtained by rotational spectroscopy \textsuperscript{[2]}, if there is a sufficient dipole moment. Vibrational spectroscopy \textsuperscript{[3]} provides a more universal, but also more coarse-grained access to these phenomena. Our group has reported the first spectroscopic evidence of chiral recognition between constitutionally identical molecules in the gas phase \textsuperscript{[4]}. We have found a case of chiral discrimination in tetrameric aggregates of methyl lactate, where the relative configuration controls the hydrogen bond topology \textsuperscript{[5]}. In the case of alcohols, we have observed different degrees of chirality synchronization up to a quantitative chirality matching in dimers of trifluoroethanol \textsuperscript{[6]}. These discoveries became possible through the use of a powerful combination of FTIR spectroscopy and high-throughput, pulsed supersonic nozzle expansions into large vacuum chambers \textsuperscript{[7]}. The isolated and elementary character of the investigated molecular assemblies is favourable for quantum chemical treatments \textsuperscript{[8]}. Valuable benchmarks for the modeling of more complex chiral recognition phenomena are thus established.\textsuperscript{1}

\begin{itemize}
  \item \textsuperscript{1}Spectroscopy and dynamics of molecular coils and aggregates (www.pcgg.de)
\end{itemize}

Thursday, June 7, 2007 10:30AM - 1:30PM —
Session H2 Undergraduate Research Session  TELUS Convention Centre Macleod D

10:30AM H2.00001 New Active Feedback Scheme for Minimization of Instrumental Asymmetries\textsuperscript{1}, MAYA FABRIKANT, University of Nebraska-Lincoln — Chiral effects in nature exist but are generally difficult to detect. A University of Nebraska Lincoln experiment to detect electron circular dichroism by sending polarized electrons through a chiral medium has met with difficulties in reducing the instrumental asymmetry below the expected true asymmetry of $\sim 10^{-4}$. In order to minimize this false asymmetry, a new optical apparatus designed for the production of polarized electrons as been built. It is based on the fast chopping of two spatially separated beams of light with orthogonal linear polarizations which are recombined and passed through a quarter wave plate to yield a single beam with rapidly flipping helicity. New methods for measuring the helicity-dependent intensity asymmetry in this apparatus have been developed. These methods show that the main reason for large instrumental asymmetries is drift due to laser polarization instability. Active electro-optical feedback has been successfully employed to maintain this asymmetry below $2 \times 10^{-5}$\textsuperscript{1}.

\begin{itemize}
  \item \textsuperscript{1}Funding for this project was provided by Undergraduate Creative Activities and Research Experiences (UCARE) and the National Science Foundation (PHY-0354946)
\end{itemize}

11:06AM H2.00002 Photodetachment Spectroscopy of Ce\textsuperscript{−}\textsubscript{4}\textsuperscript{1}, COREY JANCZAK, Denison University — The lanthanide series of negative ions provides interesting challenges and rich spectroscopic results for experiment and theory alike. A 12keV Ce\textsuperscript{−} beam has been used in perpendicular arrangement with tunable radiation from an Nd:YAG pumped OPPO laser to perform laser photodetachment spectroscopy. The quantity of photodetached neutrals has been measured as a function of photon energy in order to determine the relative cross section for neutral production. Within the range 0.5eV – 0.75eV, the spectrum exhibits five sharp peaks in addition to broad threshold behavior. The energies and widths of these resonances will be used to further explain the discrepancies between standing theoretical \textsuperscript{[1]} and experimental \textsuperscript{[2]} values for the electron affinity.

\begin{itemize}
  \item \textsuperscript{1}S.M. O’Malley and D.R. Beck, PRA 61, 034501 (2000), 74, 042509 (2006); X. Cao and M. Dolg, PRA 69, 042508 (2004).
  \item \textsuperscript{2}V.T. Davis and J.S. Thompson, PRL 88, 073003 (2002).
\end{itemize}

\begin{itemize}
  \item \textsuperscript{1}This material is based on work supported by the National Science Foundation under Grant Nos. 0140233 and 0456916.
\end{itemize}

11:42AM H2.00003 Determination of the Ps-He Momentum-transfer Cross-section Using Time Resolve Doppler Broadening, ANNA LEGARD, St. Olaf College — This experiment uses Doppler broadening to analyze the thermalization of Positronium (Ps) in Helium gas in order to calculate the momentum-transfer cross-section of Ps. There is wide variation in previous experimental and theoretical results and so this experiment seeks to improve the measurement of this value. Tracking the thermalization of Ps atoms contained within a He gas chamber, Doppler Broadening is used to determine the average energy of Ps with respect to time. From the analysis of this energy as a function of time we can fit the data with a theoretical thermalization model and from this model determine the cross-section of Ps on He. Our work this summer has yielded a value for this cross-section, including work done to determine the corresponding error bars.

12:18PM H2.00004 Trapping Single Krypton Atoms for Radioactive Background Measurements, MICHAEL MASTROIANNI, Union College — We report on the construction of an apparatus for the trapping and detection of single metastable krypton atoms, which will be used to measure krypton contamination in other rare gases by Atom Trap Trace Analysis (ATTA). A beam of atoms excited to the $5s3\textsuperscript{3}P_2$ metastable state are decelerated in a Zeeman slowing magnet, and loaded into a magneto-optical trap, where their fluorescence is detected using an avalanche photodiode. We estimate that the system will enable us to measure krypton contamination at the $3 \times 10^{-14}$ level in three hours of integration, which is close to the level required for proposed astrophysical detectors using liquid rare gases as a scintillation medium. We will discuss the trap loading and detection efficiency, and possible improvements through the use of an optically excited metastable atom source.
12:54PM H2.00005 Isotopic effects in bond rearrangement caused by sudden ionization of ammonia and methane molecules, ELI PARKE, Kansas State University — The production of H$_3^+$ and H$_5^+$ fragments upon dissociation of ammonia and methane molecules involves rearrangements of the Liouville surface. Fast ion impact results in ionization on time scales of 10 femtoseconds, thus freezing the nuclear motion. Our earlier studies of H$_3^+$ formation upon dissociation of water molecules by fast ions showed a strong isotopic dependence. Recently, we measured isotopic effects in the production rate of H$_3^+$ and H$_5^+$ from NH$_3$ and CH$_4$ ionized by the same ions. Compared to H$_3^+$, creating H$_5^+$ requires the rapid cleavage and formation of additional bonds. The process is enhanced, however, by the geometrical similarity of the parent molecules and the triangle-shaped H$_5^+$ ions. Differences in triangle size result in vibrational excitation and may cause isotopic differences.

Thursday, June 7, 2007 10:30AM - 12:54PM –
Session H3 Ultracold Atoms: Mott Insulators

10:30AM H3.00001 Rotating bosonic ring lattice: Entanglement, Mott and Lifshitz-like Transitions, ANA MARIA REY, ITAMP, Harvard-Smithsonian Center of Astrophysics, KEITH BURNETT, Clarendon Laboratory, University of Oxford, IN-DUBALSA SATIJA, George Mason University, CHARLES CLARK, NIST — We study the effects of rotation on one-dimensional ultra-cold bosons confined to a ring lattice. In this talk we discuss the existence of a critical rotation frequency at which an infinitesimal interatomic interaction energy fragments the ground state of integer filled (commensurate) systems into a macroscopic superposition of two states with different circulation. The formation of such an entangled cat state is accompanied by an opening of a gap in the spectrum and a sudden rearrangement of the momentum distribution. These features are reminiscent of the topological changes in the Fermi surface that occurs in the Lifshitz transition in fermionic systems. The entangled nature of the ground state induces a strong enhancement in the quantum correlations and decreases the threshold of the Mott insulator transition. In contrast to the commensurate case, the incommensurate lattice is rather insensitive to rotation. In addition we discuss the usefulness of noise correlations as a tool for identifying novel physics in strongly correlated systems.

10:42AM H3.00002 Mott-insulator shells in the three-dimensional Bose-Hubbard model with harmonic confinement, MAKOTO YAMASHITA, NTT Basic Research Laboratories — Ultracold atomic gases in optical lattices provide the ideal stages for investigating the fundamental many-body problems in condensed-matter physics. Recently, the superfluid-Mott insulator (MI) transition of a Bose-Einstein condensate in a three-dimensional optical lattice was precisely measured by using a two-photon spectroscopy. It has been found that, in the strong interaction regime, the number of atoms at the lattice sites takes the integer values ranging from one to five and its spatial distribution forms the shell structure, namely MI shells. To quantitatively understand these experimental results, we numerically study the ground-state properties of the three-dimensional (3D) Bose-Hubbard model with harmonic confinement. We have developed the highly efficient numerical method based on the Gutzwiller approximation, which can be applied to a large system consisting of more than one million of lattice sites. The MI shells observed in the experiments are successfully reproduced by the calculations using the appropriate parameters. We show the systematic analyses of the 3D Bose-Hubbard model and compare them with the recent experimental results.

10:54AM H3.00003 Vortices, antivortices and superfluid shells separating Mott-insulating regions, KAUSHIK MITRA, C.J. WILLIAMS, C.A.R. SA DE MELO, Joint Quantum Institute, NIST, Gaithersburg and University of Maryland, College Park — Atomic or molecular bosons in harmonically confined optical lattices are known to exhibit a wedding cake structure consisting of insulating (Mott) shells. We show that between the Mott regions, superfluid shells emerge as a result of fluctuations due to finite hopping. It is found that the order parameter equation in the superfluid regions is not of the Gross-Pitaevskii type except near the insulator to superfluid boundaries. The excitation spectra in the Mott and superfluid regions are obtained, and it is shown that the superfluid shells possess low energy sound modes with spatially dependent sound velocity described by a local index of refraction directly related to the local superfluid density. Lastly, the Berezinski-Kosterlitz-Thouless transition and vortex-antivortex pairs are discussed in thin (wide) superfluid shells (rings) limited by three (two) dimensional Mott regions. The transition temperature of each superfluid region is dependent on the filling factor of the Mott shells that limit their boundaries.

11:06AM H3.00004 Many-Body Dynamics of Repulsively Bound Pairs of Particles in a Periodic Potential, DAVID PETROSYAN, Institute of Electronic Structure & Laser, FORTH, 71110 Heraklion, Crete, Greece, BERND SCHMIDT, JAMES R. ANGLIN, MICHAEL FLEISCHHAUER, Fachbereich Physik, Technische Universitaet Kaiserslautern, 67663 Kaiserslautern — We study the effects of repulsive interactions on the formation of bound states in a periodic potential. By using the Gutzwiller approximation, we show that the formation of bound states is possible even in the strong interaction regime. We also discuss the implications of our results for the dynamics of ultra-cold atomic gases in optical lattices.

11:18AM H3.00005 Cavity QED determination of atomic number statistics in optical lattices, DOMINIC MEISER, JILA, WENZHOU CHEN, PIERRE MEYSTRE, University of Arizona — The number statistics of atoms in an optical lattice contain valuable information about their many-particle state. Usually the number statistics are difficult to measure experimentally. In this talk we present a method to measure the number statistics by means of reflection of a quantized light field off the atomic lattice inside a high-$Q$ ring resonator. Depending on the lattice spacing, the light field is sensitive to various density-density correlations of the atoms. We discuss the cases of atoms in a Mott insulator state and atoms in a superfluid state and show how the two can be distinguished with our scheme.

11:30AM H3.00006 BCS-BEC Crossover: Critical Temperature Curve and Thermodynamics, EUGENY KOZIK, BARBARA CAPOGROSSO-SANSONE, NIKOLAY PROKOF’EV, BORIS SVISTUNOV, University of Massachusetts — The strongly-correlated regime of the BCS-BEC crossover can be realized by diluting a system of two-component fermions with a contact attractive interaction and an appropriate ultraviolet regularization. We investigate this system via a novel systematic-error-free continuous-space-time diagrammatic determinant Monte Carlo method. The results allow us to predict the universal curve $T_c/k_B$ as a function of the parameter $k_F a$ with the maximum on the BCS side. At unitarity, $T_c/k_B = 0.152(7)$. We also determine the thermodynamic functions and show how the Monte Carlo results can be used for accurate thermometry.
11:42AM H3.00007 Phase diagram of the two-leg Bose-Hubbard model\textsuperscript{1} . IPPEI DANSHITA, NIST, Gaithersburg, MD 20899, JAMES E. WILLIAMS, Wolfram Research, Champaign, IL 61820, CARLOS A. R. SA DE MELO, Georgia Institute of Technology, Atlanta, GA, CHARLES W. CLARK, NIST, Gaithersburg, MD 20899 — Recently, double-well optical lattices have been created to trap bosonic atoms [J. Sebby-Strabley et al., Phys. Rev. A 73, 033605 (2006)]. In the present work, we study the superfluid-to-Mott insulator transition of bosons in double-well optical lattices. Applying the time-evolving block decimation algorithm [G. Vidal, Phys. Rev. Lett. 93, 040502 (2004); cond-mat/0605957] to the two-leg Bose-Hubbard Hamiltonian, we obtain the zero-temperature phase diagrams and find that there are the half-integer-filling and integer-filling Mott insulator regions. For symmetric double wells (no tilt), we show that the half-integer-filling Mott insulator phase is stabilized and that the integer-filling Mott insulator domain becomes smaller as the intra-double-well hopping increases. As the tilt of the double-wells increases, we find that the half-integer-filling Mott insulator phase becomes larger monotonically and approaches the integer-filling Mott phase for a single 1D lattice. In contrast, we show that the integer-filling Mott phase shows non-monotonic reentrant behaviour as a function of the tilt parameter.

\textsuperscript{1}I.D. is supported by a Grant-in-Aid from JSPS.

11:54AM H3.00008 Heisenberg limited sensitivity via transition from a two-component Mott insulator to a superfluid\textsuperscript{1} . MIRTA RODRIGUEZ, Present address: ICF-Institut de Ciencies Fotoniques, 08860 Castelldefels (Barcelona), Spain, STEPHEN CLARK, DIETER JAKSCH, Clarendon Laboratory, University of Oxford, Parks Road, Oxford OX1 3PU, U.K. — We analyze the outcome of a Mott insulator to superfluid transition for a two-component Bose gas with two atoms per site in an optical lattice in the limit of slow ramping down the lattice potential. We manipulate the initial state of the atoms in the Mott insulating regime and study how local correlations between hyperfine states of atom pairs transform into multiparticle correlations extending over the whole system. We show that under particular conditions one can create twin Fock and macroscopic superposition states and that in general, the superfluid states obtained in this way are highly depleted and present a complicated structure.

\textsuperscript{1}This work has been funded by the EPSRC and the Spanish MCyT.

12:06PM H3.00009 Preparing and probing few-atom number states with an atom interferometer\textsuperscript{1} . BENJAMIN BROWN, JENNIFER SEBBY-STRABLEY, MARCO ANDERLINI, PATRICIA LEE, JQI/NIST, PHILIP JOHNSON, American University and NIST, WILLIAM PHILLIPS, TREY PORTO, JQI/NIST — We describe the controlled loading and measurement of number-squeezed states and Poisson states of atoms in individual sites of a double-well optical lattice. These states are input to an atom interferometer that is realized by symmetrically splitting individual lattice sites into double-wells, allowing atoms in individual sites to evolve independently. The two paths then interfere, creating a matter-wave double-slit diffraction pattern. The time evolution of the double-slit diffraction pattern is used to measure the number statistics of the input state. We present investigations of three distinct site occupation distributions: predominantly one molecule at each site of an optical lattice. We now study the transport properties in the Mott-like state. A molecule can tunnel with an amplitude $J_m$ to an adjacent site. If there is already another molecule at that site the molecules can collide inelastically [2], leading to loss of both molecules from the sample. This loss occurs with a rate coefficient $\Gamma$ which is typically much faster than $J_m/h$. The fast on-site loss leads to a suppression of tunneling. Loss from the initial state effectively occurs with a rate $J_{eff} \propto J_m^2/\Gamma$. This effect is studied experimentally at different lattice depths and the results are compared with theoretical predictions.

\textsuperscript{1}This work was supported by DTO, ONR, and NASA, and the NRC and IC postdoc programs.

12:18PM H3.00010 Transport Properties of a Mott-like State of Molecules . STEPHAN DUERR, NIELS SYASSEN, DOMINIK BAUER, THOMAS VOLZ, MATTHIAS LETTNER, DANIEL DIETZE, GERHARD REMPE, Max-Planck-Institute for Quantum Optics, Hans-Kopfermann-Str. 1, 85748 Garching, Germany — In Ref. [1] we showed the preparation of a Mott-like state of molecules. This state is a quantum state with exactly one molecule at each site of an optical lattice. We now study the transport properties in the Mott-like state. A molecule can tunnel with an amplitude $J_m$ to an adjacent site. If there is already another molecule at that site the molecules can collide inelastically [2], leading to loss of both molecules from the sample. This loss occurs with a rate coefficient $\Gamma$ which is typically much faster than $J_m/h$. The fast on-site loss leads to a suppression of tunneling. Loss from the initial state effectively occurs with a rate $J_{eff} \propto J_m^2/\Gamma$. This effect is studied experimentally at different lattice depths and the results are compared with theoretical predictions.


12:30PM H3.00011 Measurements of Collective Modes Spanning the 3-D Superfluid to Mott-Insulator Transition . DAVID MCKAY, MATT WHITE, MATT PASIENSKI, YUTAKA MIYAGAWA, BRIAN DEMARCO, University of Illinois at Urbana-Champaign — We report measurements on the collective modes of a $^{87}$Rb Bose-Einstein condensate transferred into a 3-D optical lattice. We measure the frequency and damping rates of dipole and quadrupole oscillations across a range of lattice depths, from the regime of pure superfluid to coexisting superfluid and Mott-insulator phases. We will discuss relevance to the transport properties of the Bose-Hubbard model, including possible bearing on the existence of a Bose metal. We will also comment on significance to recent predictions of collective mode frequencies for superfluid shells bounded by Mott-insulator phases.

12:42PM H3.00012 Progress Toward Realizing the Superfluid to Mott-Insulator Transition in the Presence of Fine-Grain Disorder . MATTHEW PASIENSKI, MATTHEW WHITE, DAVID MCKAY, YUTAKA MIYAGAWA, BRIAN DEMARCO, University of Illinois at Urbana-Champaign — We report on experimental progress toward realizing the superfluid to Mott-insulator transition in the presence of fine-grain disorder. Disorder is added—using a speckle field created by a holographic diffuser—to a $^{87}$Rb Bose-Einstein condensate trapped in a 3-D optical lattice. We are able to achieve speckle sizes of 700 nm, less than twice the lattice spacing, by employing low f/# optics and 532 nm light.

Thursday, June 7, 2007 10:30AM - 1:06PM – Session H4 Two and Few-body Collisions of Ultracold Atoms and Molecules TELUS Convention Centre Glen 206
A new method for calculation of Efimov resonances. CHENG CHIN, James Franck Institute and Physics Department, University of Chicago — Recent experiments on ultracold Feshbach molecules have revealed states in ultracold quantum gases. These results — the latter in particular — address the increasingly relevant and interesting question of the behavior of Efimov states. We use the adiabatic hyperspherical representation and obtain the four-body adiabatic hyperspherical potentials by treating the interactions between the atoms in the Efimov state and the fourth atom perturbatively via a Fermi contact potential with an energy-dependent scattering length. These adiabatic potentials are then used to determine the binding energies of the tetra-atomic molecules which, in turn, allow us to determine the combinations of scattering length and effective range that result in binding. These molecules are expected to have long lifetimes and could be detected in ultracold gases of 85Rb, as well as 133Cs at high fields in the vicinity of 800 G.

Acknowledgment is made to the Donors of the American Chemical Society Petroleum Research Fund for support of this research.

Supported by the National Science Foundation.

This work is by supported CNRS and NWO.

Ultracold four-body collisions of two-spin fermionic atoms. JOSE P. D'INCAO, NIRAV P. MEHTA, JILA, University of Colorado, Boulder, SETH T. RITTENHOUSE, CHRIS H. GREENE, Department of Physics and JILA, University of Colorado, Boulder — We have performed ab initio calculations for the four fermion system in two different spin states. From these calculations we were able to extract the scattering length dependence for the scattering observables which are relevant for current experiments in ultracold fermionic quantum gases. We have calculated, for instance, the dimer-dimer scattering length and explored the finite energy dependence concerning the experimental range of temperatures in the strongly interacting regime. Due to the finite range of our interatomic model we were also able to explore finite scattering length corrections to the dimer-dimer scattering length. This work was supported by the National Science Foundation.

Ultracold Feshbach molecules: energy structure and scattering length. CHENG CHIN, James Franck Institute and Physics Department, University of Chicago — Recent experiments on ultracold Feshbach molecules have revealed detailed and intriguing molecular energy structure near the continuum. Based on the quantum nature of the molecules, they are generally classified into two types: open-channel dominated and closed channel dominated. A simple picture exists to unify and describe both types of molecules.

We report excellent agreement between our results and the full multi-channel calculation over a wide range of molecular binding energies: from 0 (continuum) to \( \hbar \times 1 \text{GHz} \). Comparison to measurements on \( ^{6} \text{Li} \), \( ^{40} \text{K} \), \( ^{85} \text{Rb} \), \( ^{87} \text{Rb} \) and \( ^{133} \text{Cs} \) will be presented. In particular, we will discuss the issue of associating molecular binding energies and atomic scattering lengths and the case of \( ^{133} \text{Cs} \) where multiple s-, d- and g-wave resonances overlap.

C.C. acknowledges support from Chicago MRSEC and Sloan Fellowship.

12:06PM H4.00009 Calculation of the two-body scattering T-matrix in Configuration Space. GEORGE RAWITSCHER, University of Connecticut — Three-body Faddeev calculations require as input two-body T-matrices. For atomic physics applications configuration space is preferable over momentum space, since the potentials are given in the former. A recently developed solution of the Lippmann-Schwinger integral equation for the one-variable scattering wave function in configuration space [1] has now been extended to obtain the two variable scattering T-matrix, as will be shown with numerical examples. The method is based on spectral expansions into Chebyshev Polynomials of two auxiliary functions in each radial partition, in terms of which the T-matrix is obtained. The result is an important ingredient for the solution of the Faddeev integral equations in configuration space [2]. [1] G. Rauitscher and I. Koltracht, Computing in. Sc. and Eng., 7, 58 (2005); [2] W. Glöckle, and G. Rawitscher; “Three-atom scattering via the Faddeev scheme in configuration space,” physics/0512010 at arxiv.com;

12:18PM H4.00010 A Measurement of the s-Wave Scattering Length in a 7Li Bose-Einstein Condensate. 1. D. DRIES, M. JUNKER, J. HITCHCOCK, C. WELFORD, Y.P. CHEN, R.G. HULET, Department of Physics and Astronomy and Rice Quantum Institute, Rice University — The s-wave scattering length, $a_s$, parameterizes the effective interatomic interactions in a Bose-Einstein condensate (BEC). The sign and magnitude of $a_s$ have important consequences for the observable properties of the condensate and, consequently, $a_s$ needs to be accurately known in order to correctly interpret many experimental results. In our experiment, we create an optically trapped 7Li BEC in the $F = 1$, $m_F = 1$ hyperfine state. Using a Feshbach resonance, we are able to change the value of $a_s$ by nearly two orders of magnitude over the magnetic field range of 507-730 G. We extract $a_s$ from absorption images of the condensate by fitting to the Thomas-Fermi radius. Furthermore, the condensate suddenly disappears at fields above 730 ± 1 G, placing a lower bound on the location of the Feshbach resonance.

1Supported by the NSF, ONR, and the Welch and Keck Foundations.

12:30PM H4.00011 Isotopic tuning of scattering lengths of ultracold Yb atoms. PAUL JULIENNE, NIST, R. CIURYLO, Nicolas Copernicus University, M. KITAGAWA, K. ENOMOTO, K. KASA, Y. TAKAHASHI, Kyoto University — The species Yb has 5 stable spinless bosonic isotopes and two fermionic ones, $^{171}$Yb with $I=1/2$ and $^{173}$Yb with $I=5/2$. Two-color photoassociation spectroscopy of ultracold Yb atomic gases has been used to measure the binding energies of 7 J=0 and 5 J=2 bound states near the dissociation threshold of the homonuclear molecular dimers $^{171}$Yb$_2$, $^{171}$Yb$_2$, $^{172}$Yb$_2$, $^{171}$Yb$_2$, $^{174}$Yb$_2$, and $^{176}$Yb$_2$. Fitting 3 binding energies from $^{174}$Yb$_2$ and $^{176}$Yb$_2$ determines the $C_0$ and $C_6$ van der Waals constants and the absolute number of bound states in the singlet ground state potential. Our mass-scaled model then accurately predicts the binding energies of the other 9 measured levels, and determines accurate scattering lengths of all 28 different isotopic combinations, including $^{188}$Yb. As the reduced mass varies from 168/2 to 176/2, the scattering lengths vary through a complete cycle from $-\infty$ to $+\infty$. Thus, scattering length can be widely “tuned” by varying isotopic composition. Since all 6 species from mass 170 to 176 can be brought to the quantum degenerate regime, this gives a wide variety of mixtures for new studies of ultracold quantum gases and lattices.

12:42PM H4.00012 High Intensity 2-Photon Photoassociation Spectroscopy of Strontium. S.B. NAGEL, Y.N. MARTINEZ, P.G. MICKELSON, T.C. KILLIAN, Rice University — We perform high intensity, 2-photon photoassociation spectroscopy near the 461 nm $^1S_0-^1P_1$ transition of strontium to determine the binding energy of the least bound level in the ground state atomic potential. Previous work by our group has constrained the value of the s-wave scattering length in both $^{88}$Sr and $^{86}$Sr. This work provides a more precise value of the s-wave scattering lengths using the newly-determined binding energy, thus informing efforts to attain quantum degeneracy in strontium.

12:54PM H4.00013 Three-body physics with multichannel two-body interactions. NIRAV MEHTA, JILA, University of Colorado, Boulder CO, 80309, SETH RITTENHOUSE, JILA and Dept. of Physics, University of Colorado, Boulder CO, 80309, JOSE D'INCAO, JILA, University of Colorado, Boulder CO, 80309, CHRIS GREENE, JILA and Dept. of Physics, University of Colorado, Boulder CO, 80309 — Atoms with internal hyperfine states (denoted by A, A', etc.) split by an external magnetic field are governed by complicated multichannel pair-wise interactions. We consider a simplified zero-range multichannel model designed to mimic atom-atom scattering near a Feshbach resonance. Our simple two-body interaction with internal hyperfine states (denoted by A, A', etc.) split by an external magnetic field are governed by complicated multichannel pair-wise interactions. This work was supported in part by the National Science Foundation.

Thursday, June 7, 2007 10:30AM - 12:54PM – Session H5 Decoherence, Entanglement, and Chaos TELUS Convention Centre Glen 205
10:30AM H5.00001 Coherent control and entanglement in a decoherence-free subspace of two multi-level atoms , MARTIN KIFFNER, JÖRG EVERS, CHRISTOPH H. KEITEL, Max-Planck-Institute for Nuclear Physics, Saupfercheckweg 1, 69117 Heidelberg, Germany — Decoherence-free subspaces (DFS) in a system of two dipole-dipole interacting multi-level atoms are investigated theoretically. The ground state of each atom is a \( S_0 \) singlet state, and the excited state multiplet is a \( F_3 \) triplet. Since we consider arbitrary geometrical alignments of the atoms, all Zeeman sublevels of the atomic multiplets have to be taken into account [1]. It is shown that the collective state space of the two dipole-dipole interacting four-level atoms contains four-dimensional DFS [2]. We describe a method that allows to populate the antisymmetric states of the DFS by means of a laser field. These antisymmetric states are identified as long-lived entangled states. Further, we show that any single-qubit operation between two states of the DFS can be induced by means of a microwave field. Typical operation times of these qubit rotations can be significantly shorter than for a nuclear spin system.


10:42AM H5.00002 Neutral atoms with cavity-assisted interaction for robust long distant quantum communication , PENG XUE, Institute for quantum information science, University of Calgary, INSTITUTE FOR QUANTUM INFORMATION SCIENCE, UNIVERSITY OF CALGARY TEAM — We show how to realize long distance quantum communication with long-lived quantum memories, acting on decoherence-free subspace (DFS), with neutral atoms whose interactions are catalyzed by single photons, or weak coherent light. In this matter, generation, purification and swapping of logical entangled states are obtained through cavity-assisted photon scattering that is robust to random variation in the atom-photon coupling rate, thereby avoiding the requirement for location in the Lamb-Dicke regime. The logical qubits are immunized to the dominant source of decoherence; while, additional errors as photon losses in our scheme are automatically detected, leading to signaled errors which do not affect the fidelity of the logical entanglement. Our scheme is also robust to the changes in the path lengths during long distance communication since no interferometer is required here. We show it can be implemented in the context of prominent experimental setups for quantum information processing.

The acknowledgments support from iCORE.

11:06AM H5.00004 Criteria for dynamically stable decoherence-free subspaces , R. KARASIK, BQIC and Applied Science & Technology, Univ. of California, Berkeley, K.-P. MARZLIN, B.C. SANDERS, IQIS, Univ. of Calgary, Canada, K.B. WHALEY, BQIC and Dept. of Chemistry, Univ. of California, Berkeley — A decoherence-free subspace (DFS) is a collection of states for a system that is impervious to dominant noise effects created by the environment. The DFS approach provides an important strategy for quantum information processing because it would allow quantum circuit simplification by reducing the need for quantum error correction and providing stable quantum memory. Experimental demonstrations of DFSs show the efficacy of this approach. We analyze similarities and differences between various approaches to DFSs present in the literature and show that an excessively restrictive assumption on immunity from decoherence for an arbitrary initial environment state can be relaxed for practical DFS cases. In the important class of systems whose dynamics is described by Markovian master equations, we provide necessary and sufficient conditions for the existence of a dynamically stable DFS. We also present examples that show why previous work in this direction was not sufficient.

11:18AM H5.00005 Robust transmission of non-Gaussian entanglement over optical fibers , ASOKA BISWAS, DANIEL A. LIDAR, University of Southern California — We show how the entanglement in a wide range of continuous variable non-Gaussian states can be preserved against decoherence for long-range quantum communication through an optical fiber. We apply protection via decoherence-free subspaces and quantum dynamical decoupling to this end. The latter is implemented by inserting phase shifters at regular intervals \( \Delta \) inside the fiber, where \( \Delta \) is roughly the ratio of the speed of light in the fiber to the bath high-frequency cutoff. Detailed estimates of relevant parameters are provided using the boson-boson model of system-bath interaction for silica fibers, and \( \Delta \) is found to be on the order of a millimeter.

11:30AM H5.00006 Decoherence-induced geometric phase in an open multilevel atomic system , SHUBHRANGSHU DASGUPTA, University of Toronto, DANIEL A. LIDAR, University of Southern California — We consider the process of stimulated Raman adiabatic passage (STIRAP) in a three-level system. Viewed as a closed system, no geometric phase is acquired. But in the presence of spontaneous emission and/or collisional relaxation we show numerically that a non-vanishing, purely real, geometric phase is acquired during STIRAP, whose magnitude grows with the decay rates. Rather than viewing this decoherence-induced geometric phase as a nuisance, it can be considered an example of beneficial decoherence: the environment provides a mechanism for the generation of geometric phases which would otherwise require an extra experimental control knob.

11:42AM H5.00007 Studying chaos, entanglement and decoherence in the quantum kicked top with cold atoms , SHOHINI GHOSE, Wilfrid Laurier University, RENE STOCK, Institute for Quantum Information Science, University of Calgary, ROSHAN LAL, Indian Institute of Technology, ANDREW SILBERFARB, Aarhus University — We propose and analyze an experiment to study the dynamics of the quantum kicked top using cold Ceium atoms interacting with laser and magnetic fields. This would be the first experimental realization of this well known chaotic system in a deeply quantum regime, and would allow detailed studies of the effects of chaos on entanglement and decoherence. These studies are of importance for understanding quantum-classical correspondence as well as for designing quantum information processing applications. We describe the process of state preparation in the system, and show how the nonlinear AC Stark shift together with a pulsed magnetic field can be used to realize the kicked top Hamiltonian. Signatures of chaos are evident in the entanglement between the electronic and nuclear spin, which can be monitored via Faraday rotation spectroscopy. We analyze and explain the predicted dynamics by decomposing the initial states into regular and chaotic Floquet eigenstates. Our accurate simulations show that dynamical signatures of chaos persist in the presence of decoherence due to photon scattering. Furthermore, chaos affects the decoherence rate itself due to the rapid mixing in phase space caused by chaotic dynamics, even in a deeply quantum regime.

The acknowledgments support from iCORE.
11:54AM H5.00008 Chaos and Entanglement with Two Coupled Spins. LEIGH NORRIS, PARIN SRI-PAKDEEVONG, ARJENDU PATTANAYAK, Carleton College, COLLIN TRAIL, IVAN DEUTSCH, University of New Mexico, SHOHINI GHOSE, Wilfrid Laurier University — We study the correlation between chaos and entanglement in a system consisting of two spins that evolve via hyperfine and Zeeman interactions in the presence of a time-varying external magnetic field. Here, chaos arises due to the coupling between subsystems, in contrast with previously studied cases where two coupled subsystems are independently chaotic (e.g. coupled kicked tops). Using a common Hamiltonian to generate quantum and classical dynamics, we study how the entanglement generated by initially uncoupled spin-coherent states correlates with the mixed nature of the underlying classical phase space consisting of regular islands and a chaotic sea. We report on the relationship between the mean entanglement of the eigenstates of the Floquet operator and the presence of chaos in the classical phase space. We also analyze the performance of an entanglement measure dependent on the eigenvalues of the Floquet operator.

12:06PM H5.00009 Chaotic Escape of Particles from a Vase-Shaped Billiard. JAISON NOVICK, College of William and Mary, JOHN DELOS, Collge of William and Mary, KEVIN MITCHELL, University of California, Merced — We study the escape of particles from a two dimensional, open billiard with the shape of a vase. At the narrowest point of the vase’s neck lies an unstable periodic orbit that defines a dividing surface between orbits that escape and those that are turned back into the cavity. We imagine a burst of particles emanating from a point source with all possible launch angles. We show that the particles arrive at the detector in pulses. We record the time for escaping particles to reach the dividing surface. The escape time, as a function of the launch angle, displays a fractal structure that is understood upon transformation to a suitable phase space. Here, we find two infinitely long, invariant curves, called stable and unstable manifolds, emanating from the unstable fixed point. These curves intersect in a complicated way forming a structure known as a homoclinic tangle. The intersection of the initial conditions with the tangle produces the escape time fractal. We present a topological method that, given a finite development of the tangle, allows us to predict a subset of the fractal seen in numerical experiments.

12:18PM H5.00010 ABSTRACT HAS BEEN MOVED TO R1.00096

12:30PM H5.00011 Dynamically Invariant Entanglement in Particle Collisions. NATHAN HARSHMAN, Physics Program, American University — When most people think of entanglement, they think of interparticle entanglement. For example, how is Alice’s particle correlated to Bob’s particle? However, other kinds of entanglement can be defined. Any partition of a complete set of commuting observables implies a tensor product structure, and therewith, a kind of entanglement. These other kinds of entanglement can be useful for understanding particles and the generation of entanglement in collisions. For example, only certain kinds of entanglement are invariant under a change of reference frame. In particular, the entanglement between internal and external degrees of freedom is invariant and it is conserved in collisions.

The author acknowledges the support of the Research Corporation.

12:42PM H5.00012 Entanglement of mixed states in systems of n qubits. RENAN CABRERA, WILLIAM BAYLS, Physics Dept., Univ. of Windsor — With the help of geometric algebra, we define a sequence of unitary operators that fulfills a controllability condition and whose operation on a reference or pass state spans the complete Hilbert space. The unitary operators can be classified according to their ability to induce entanglement, and the operators that can entangle a system provide a natural parametrization of the process. The entanglement of pure states is measured using reduced traces, and this can be extended to define a measure of the entanglement of mixed states in a system of n qubits. Practical expressions for average state fidelity of n-qubit systems have also been obtained.

1Support of research by NSERC is gratefully acknowledged.

Thursday, June 7, 2007 10:30AM - 12:54PM – Session H6 Atomic Structure and Spectroscopy TELUS Convention Centre Olde Scotch Room

10:30AM H6.00001 Spectroscopy of Atomic Systems under Plasma Environment. AMAR NATH SIL, Indian Association for the Cultivation of Science, Jadavpur, Kolkata 700 032, India, S. FRITZSCHE, Institut für Physik, Universität Kassel, 34109 Kassel, Germany, P. K. MUKHERJEE, Indian Association for the Cultivation of Science, Jadavpur, Kolkata 700 032, India — Extensive model calculations have been performed to study the effect of plasma on the structural properties like ground and excited energy levels, dipole polarizabilities, oscillator strengths, transition probabilities of hydrogen and helium like systems. For weak coupling case Debye screening model and for strong coupling case Ion Sphere model of the plasma have been applied. We studied in particular the hydrogen like carbon, aluminium and argon and helium like carbon under different plasma coupling strengths. Time dependent linear response theory has been utilized in finding the excitation properties of the ionic systems under such plasma conditions. The spectral line shifts have been calculated and ionization pressure has been estimated using finite boundary conditions imposed on the wave functions. It is noted that with finite plasma coupling the ionization potential decreases and the number of excited states become finite. The system approaches towards instability gradually as the strength of the coupling is increased. Theoretical estimates of the spectral line positions under such plasma for several hydrogen like systems seem to be in very good agreement with the experimental observations with laser produced plasmas.

10:42AM H6.00002 Relativistic coupled-cluster single-double method applied to alkali-metal atoms. RUPI PAL, M.S. SAFRONOVA, University of Delaware, W.R. JOHNSON, University of Notre Dame, ANDREI DEREVIANKO, University of Nevada, Reno, SERGEY G. PORSEV, University of Nevada, Reno and Petersburg Nuclear Physics Institute, Russia — A relativistic version of the coupled-cluster single-double (CCSD) method is developed for atoms with a single valence electron. In earlier work, a linearized version of the CCSD method (with extensions to include a dominant class of triple excitations) led to accurate predictions for energies, transition amplitudes, hyperfine constants, and other properties of monovalent atoms. Further progress in high-precision atomic structure calculations for heavy atoms calls for improvement of the linearized coupled-cluster methodology. In the present work, equations for the single and double excitation coefficients of the Dirac-Fock wave function, including all non-linear coupled-cluster terms that contribute at the single-double level are worked out. Contributions of the non-linear terms to energies, electric-dipole matrix elements, and hyperfine constants of low-lying states in alkali-metal atoms from Li to Cs were systematically investigated. The effect of the core non-linear terms was found to be not negligible for heavier alkalies, reaching nearly 1% of the total values of the Cs hyperfine constants. The final results are compared with other calculations and with precise experiments.
10:54AM H6.00003 Excitation energies, hyperfine constants, transition rates, and lifetimes of $5s^2nl$ states in In I and Sn II. U.I. SAFRONOVA, University of Nevada, Reno. M.S. SAFRONOVA, University of Delaware, M.G. KOZLOV, Petersburg Nuclear Physics Institute. Energies of $5s^5p_{2p}$ ($n = 5-8$), $5s^5s_{1/2}$ ($n = 6-9$), $5s^5d_{j}$ ($n = 5-8$), and $5s^5f_{j}$ ($n = 4-5$) states in In I and Sn II are obtained using relativistic many-body perturbation theory. Reduced matrix elements, oscillator strengths, transition rates, and lifetimes are determined for the 102 observable $5s^5nl - 5s^5nl'$, electron-dipole and magnetic dipole transition rates. Electric-quadrupole and magnetic-dipole matrix elements are evaluated to obtain $5s^5p_{3/2} - 5s^5p_{1/2}$ transition rates. Hyperfine constants A are evaluated for $5s^5p_{2p}$ ($n = 5-8$), $5s^5s_{1/2}$ ($n = 6-9$), and $5s^5d_{j}$ ($n = 5-8$) states in $^{115}$In and $^{117}$In. First-, second-, third-, and all-order corrections to the energies and matrix elements and first- and second-order Breit corrections to energies are calculated. In our implementation of the all-order method, single and double excitations of Dirac-Fock wave functions are included to all orders in perturbation theory. These calculations provide a theoretical benchmark for comparison with experiment and theory.

11:06AM H6.00004 Spectroscopy of $^3S_0 \rightarrow ^3P_0$ transition in In$^+$. WILLIAM TRIMBLE, WARREN NAGOUREN, University of Washington — We report spectroscopy of the $^3S_0 \rightarrow ^3P_0$ transition at 237 nm in single indium ions confined in a Paul-Strabael trap. The indium ion is among candidates for optical frequency references for higher quality factor ($Q \sim 1.5 \cdot 10^{15}$) and the small quadrupole and blackbody shifts of its ground-state to $^3P_0$ transition. Using a frequency-quadrupled diode laser to cool the ion on the stronger $^3S_0 \rightarrow ^3P_1$ transition, we report sub-kHz linewidths in exciting the narrow $^3P_0$ transition using a frequency-quadrupled Nd:YAG nonplanar ring oscillator (NPRO) at 946 nm stabilized to a vertically-mounted high-finesse ULE cavity.

11:18AM H6.00005 2p$^{-1}3s^{-1}3x^{-1}3x^{-1}3d^{-1}$ X-Ray satellites in the $L_{01}$ spectra of 4d transition elements. SURENDRAS POONIA, Research Scientist (Atomic and X-Ray Spectroscopy) — The X-ray satellite spectra arising due to $2p_{3/2}^{-1}3s^{-1}3x^{-1}3d^{-1}$ (x = s, p, d) transition array, in elements with Z = 40 to 48, have been calculated, using available Hartree-Fock-Slater (HFS) data on $1s^{-2}2p^{-1}3s^{-1}$ and $2p_{1/2}^{-1}3s^{-1}3x^{-1}3d^{-1}$ Auger transition energies. The relative intensities of all the possible transitions have been estimated by considering cross-sections for the Auger transitions simultaneous to a hole creation and then distributing the total cross sections for initial two-hole states $2p_{3/2}^{-1}3x^{-1}$ amongst various allowed transitions from these initial states to $3x^{-1}3d^{-1}$ final states by Coster-Kronig (CK) and shake-off processes. Each transition has been assumed to give rise to a Gaussian line and the overall spectrum has been compared with the sum of these Gaussian curves. The calculated spectra have been compared with the measured satellite spectra in the $L_{01}$ spectra. Their intense peaks have been identified as the observed satellite lines. The peaks in the theoretical satellite spectra were identified as the experimentally reported satellites $a_3$, $a_4$ and $a_5$, which lie on the high-energy side of the $L_{01}$ dipole line.

11:30AM H6.00006 Relativistic nuclear recoil, electron correlation and QED effects in highly charged Ar ions. Z. HARMAN, R. SORIA ORTS, A. LAPIERE, J.R. CRESPO LOPEZ-URRUTIA, A.N. ARTEMYEV, I.I. TUPITSYN, U.I. JENTSCHURA, C.H. KEITEL, H. TAWARA, J. ULLRICH, Max Planck Institute for Nuclear Physics, Heidelberg, Germany, V.M. SHABAEV, A.V. VOLOTKA, St. Petersburg State University, Russia. — We have performed extensive theoretical studies on the $1s^22s^22p^{6}2p^{-1}$ $^1P_1/2$ M1 transition in Ar$^{34+}$ ions. Accurate radiative lifetimes are sensitive to QED corrections like the electron anomalous magnetic moment and to relativistic electron correlation effects. The lifetime of the $P_{3/2}$ metastable state was determined to be 9.573(4)(5) ms (stat)(syst) [1] using the Heidelberg electron beam ion trap. Theoretical predictions cluster around a value that is significantly shorter than this high-precision experimental result. This discrepancy is presently unexplained. The wavelengths of the above transition in Ar$^{34+}$ and the $1s^22s^22p^{6}2p^{-1}$ $^3P_1/2$ M1 transition in Ar$^{34+}$ were compared for the isotopes $^{36}$Ar and $^{40}$Ar [2]. The observed mass shift has confirmed the relativistic theory of nuclear recoil effects in many-body systems. Our calculations, based on the fully relativistic recoil operator, are in excellent agreement with the measured results. [1] A. Lapierre, U.I. Jentschura, J.R. Crespo Lopez-Urrutia et al., Phys. Rev. Lett. 95, 183001 (2005); [2] R. Soria Orts, Z. Harman, J.R. Crespo Lopez-Urrutia et al., Phys. Rev. Lett. 97, 103002 (2006).

11:42AM H6.00007 Modeling and Spectroscopic Analysis of non-LTE Krypton Plasmas. ARATI DASGUPTA, R.W. CLARK, Y.K. CHONG, J. DAVIS, Naval Research Laboratory. — We have developed a detailed multilevel atomic model for K-, L- and M-shell krypton, and investigated its impact on the radiation hydrodynamics on a krypton gas puff driven by the redesigned Sandia National Laboratory ZR accelerator. The atomic model employs an extensive atomic level structure, which is necessary to accurately model the pinch dynamics and the spectroscopic details of the emitted radiation. The atomic data was obtained using the state-of-the-art Flexible Atomic Code, and all relevant radiative atomic processes were included in generating the model. The enormous number of fine-structure levels were judiciously lumped to create a database that is detailed but manageable. We have analyzed the behavior in the krypton K- through M-shell ionization stages using temperature and density conditions that have been predicted in 1-D and 2-D MHD calculations of implosions on ZR.

1Work supported by DTRA

11:54AM H6.00008 Absorption Lineshape Modeling of Neutral Xenon in a Magnetized Optogalvanic Cell. BAILO NGOM, TIM SMITH, ALEC GALLIMORE, University of Michigan — We present a computational model for Zeeman splitting of the 6s$^{10}[3/2]_{5/2}$ $\rightarrow$ 6p$^{10}[5/2]_{3/2}$ absorption of neutral xenon at 834 682 nm (air). The model accounts for Zeeman splitting of the xenon hyperfine structure by assuming that the extra-nuclear spin and spin-orbit wavefunctions are separable for an atomic system described by a rigid spherical spinning body in a central force field, all immersed in a magnetic field. This theoretical approach permits calculation of the intensity and displacement of Zeeman-shifted hyperfine lines for $\sigma$ and $\pi$ beam polarizations. By comparing the resulting model with previously-reported Zeeman-split optogalvanic spectra [2], we explore the utility of Zeeman splitting of laser-induced fluorescence spectra as a magnetic component intensity diagnostic in xenon electrostatic thruster plumes.


12:06PM H6.00009 Fast-ion-beam laser-induced-fluorescence measurements of oscillator strengths in doubly ionized lanthanides. RUOHONG LI, RICHARD A. HOLT, S. DAVID ROSNER, Department of Physics and Astronomy, University of Western Ontario — Accurate oscillator strength data for singly and doubly ionized lanthanides are needed in astrophysics to study the spectra of Chemically Peculiar (CP) stars, which show large overabundances of lanthanide compared to the Standard Abundance Distribution, and in nucleosynthesis studies. We have previously measured oscillator strengths in Sm II, Nd II, and Pr II using fast-ion-beam laser-induced-fluorescence methods. Our new Penning Ion Source provides us doubly-ionized ion beams to study lifetimes and branching fractions of lanthanide ions, which are actually the more abundant charge species in hot CP stars. A new GaAs photomultiplier tube gives us a greater wavelength range (185-930nm) for the detection of spontaneous emission. A new detector-substitution method of detector calibration will make the experimental accuracy significantly below 10%. Recent results will be presented.

3Supported by the Natural Sciences and Engineering Research Council of Canada
discuss an example of what we learned from subsequent studies of BCS-BEC crossover physics. Molecules. The physics is thus in the crossover between BCS superconductivity and Bose-Einstein condensation (BEC) of tightly bound pairs. Lastly, I will find the Feshbach resonance through condensation of fermionic atom pairs. The pairs here have some properties of Cooper pairs and some properties of diatomic molecules. To convert a large fraction of our fermionic atoms into bosonic molecules. By adiabatically converting a low entropy Fermi gas to such molecules, we created found and characterized. At these scattering resonances, we had the unique ability to arbitrarily tune the fermion-fermion interaction, and we discovered how this produced a lattice of semiclassical expectation values which is in good agreement with direct quantum calculations. For certain ranges of electric and magnetic field strengths and orientations the lattice contains defects connected with a subtle phenomenon of classical mechanics called monodromy. If a classical system has monodromy then there is a classical action variable which is an intrinsically multivalued function of the constants of the motion. Monodromy had been predicted to be present for perpendicular fields by Savodnik and Cushman. We show that the presence of monodromy persists in near-perpendicular fields, and that the associated lattice defects undergo a series of bifurcations. We have used classical mechanics to map out the range of lattice structure in all weak near-perpendicular field configurations from the Stark to Zeeman limits. We show that there are six different families of spectra, five of which display the effects of monodromy.

Thursday, June 7, 2007 1:30PM - 4:30PM —
Session J1 Thesis Prize Session TELUS Convention Centre Macleod BC

1:30PM J1.00001 Real-time Manipulation of Entanglement between Remote Atomic Ensembles for a Scalable Quantum Network, JAMES CHIN-WEN CHOU, California Institute of Technology — Entanglement, a uniquely quantum mechanical property of correlations among various components of a physical system, has been recognized as a critical resource in quantum information science. Besides deterministic approaches, entanglement can be created probabilistically by way of quantum interference. It is essential that the success of entanglement creation is heralded unambiguously (by a “trigger”) so that the resulting entangled state is available for subsequent operations. In addition, quantum memory is required to store the entangled states until they are needed for the protocol at hand. Combined, the “trigger” and quantum memory can lead to exponential speedup for protocols exploiting multiple components. We report the initial observation of measurement-induced entanglement between excitations stored in remote cold atomic ensembles. The resulting entangled state is heralded and stored in quantum memories. The heralded nature and quantum memory for certain quantum states are exploited to implement real-time control of the states of atomic ensembles and significantly improve the success rates of two quantum information protocols for scalable quantum networks. In one protocol, we observe the interference of two single photons from two ensembles and characterize their indistinguishability. In the other, we first prepare two pairs of entangled ensembles shared between two remote sites. The ensembles are then exploited to generate polarization-entangled photon pairs at the two remote sites, with the entanglement verified by the violation of a Bell’s inequality. The photon pairs have potential applications for entanglement-based long-distance quantum communication protocols, such as quantum key distribution and quantum teleportation.

2:06PM J1.00002 Quantum Networking with Atomic Ensembles, DZMITRY MATSUKEVICH, School of Physics, Georgia Tech — Quantum communication networks enable secure transmission of information between remote sites. However, at present, photon losses in the optical fiber limit communication distances to less than 150 kilometers. The quantum repeater idea allows extension of these distances. In practice, it involves the ability to store quantum information for a long time in atomic systems and coherently transfer quantum states between matter and light. Previously known schemes involved atomic Raman transitions in the UV or near-infrared and suffered from severe loss in optical fiber that precluded long-distance quantum communication. In this work a practical quantum telecommunication scheme based on cascade atomic transitions is proposed, with particular reference to cold alkali metal ensembles. Within this proposal, essential building blocks for a quantum network architecture are demonstrated experimentally, including storage and retrieval of single photons transmitted between remote quantum memories, collapses and revivals of quantum memories, deterministic generation of single photons via conditional quantum evolution, quantum state transfer between atomic and photonic qubits, entanglement of atomic and photonic qubits, entanglement of remote atomic qubits, and entanglement of a pair of 1530 nm and 780 nm photons. These results pave the way for construction of a realistic quantum repeater for long distance quantum communication.

2:42PM J1.00003 Experimental realization of BCS-BEC crossover physics with a Fermi gas of atoms, CINDY REGAL, JILA: NIST and the University of Colorado — In my talk I will present experiments performed with a strongly interacting Fermi gas of 40K atoms. These experiments, along with the work of groups studying the fermion 6Li, pioneered many new techniques for the study of ultracold Fermi gases and culminated in the observation of fermion pairing and superfluidity. As a first step in this work Feshbach resonances between 40K atoms were found and characterized. At these scattering resonances, we have the unique ability to arbitrarily tune the fermion-fermion interaction, and we discovered how to convert a large fraction of our fermionic atoms into bosonic molecules. By adiabatically converting a low entropy Fermi gas to such molecules, we created one of the first molecular Bose-Einstein condensates. Even more importantly I will describe how we were able to observe a phase transition near the peak of the Feshbach resonance through condensation of fermionic atom pairs. The pairs here have some properties of Cooper pairs and some properties of diatomic molecules. The physics is thus in the crossover between BCS superconductivity and Bose-Einstein condensation (BEC) of tightly bound pairs. Lastly, I will discuss an example of what we learned from subsequent studies of BCS-BEC crossover physics.
3:18PM J1.00004 Quantum Information Processing in Artificial Molecules1, JACOB TAYLOR, Massachusetts Institute of Technology — Isolated atomic and molecular systems are known for their robust coherence properties. Further, their quantum states can now be controlled with exquisite precision, which provides an excellent starting point for implementing fundamental ideas from quantum information science. In this talk, we describe recent progress in developing techniques for quantum control of artificial molecules composed of coupled semiconductor quantum dots. We first focus on the electron spin degrees of freedom associated with such systems and show that the coherence properties of electron spins are determined by hyperfine interactions with large ensembles of lattice nuclear spins. Next we determine that the fine-structure states of quantum dot molecules provides a mechanism for robust manipulation of electron spins, while coupling to nuclei can be mitigated by using local, electrical control of the system. We further consider possible applications of such systems in quantum information science. We conclude with a discussion of the long-term prospects and fault tolerance properties of semiconductor quantum dots for large scale quantum information processing.

1Thesis work performed at the Department of Physics, Harvard University, under advisor Mikhail D. Lukin

3:54PM J1.00005 High-temperature superfluidity in an ultracold Fermi gas1, MARTIN ZWIERLEIN, MIT, Cambridge, USA and Johannes-Gutenburg University, Mainz, Germany — Fermionic superfluidity occurs in a wide variety of physical systems, ranging from superconductors and helium-3 to distant neutron stars. Its realization in ultracold atomic Fermi gases provides us with a unique model system for the study of strongly interacting fermions in a clean and highly controllable environment. We have observed superfluidity in a gas of fermionic lithium-6. Strong interactions between the fermions are induced via a Feshbach resonance. This leads to the highest transition temperature relative to the Fermi temperature ever reported for a fermionic superfluid or superconductor. Scaled to the density of electrons in a metal, the superfluid transition temperature would lie far above room temperature. By varying the interatomic interaction, we can explore the crossover between two limiting cases of fermionic superfluidity: A Bose-Einstein condensate (BEC) of tightly bound molecules and a Bardeen-Cooper-Schrieffer (BCS) superfluid of long-range Cooper pairs. Condensates of up to 10 million fermion pairs are observed in a regime where pairing is purely a many-body effect, the pairs being stabilized by the presence of the surrounding particles. Superfluidity and phase coherence is directly demonstrated throughout the BEC-BCS crossover via the observation of long-lived, ordered vortex lattices in rotating Fermi gases. Further, we establish superfluidity in Fermi mixtures with imbalanced spin populations, addressing a long-standing debate on the ground state of these systems. We observe the separation of the trapped gas into a superfluid region at equal spin densities, surrounded by a shell at unequal densities. Above a certain critical imbalance, a phase transition to the normal state is identified, the Chandrasekhar-Clogston limit of fermionic superfluidity.

1This work was performed at MIT, Cambridge, USA. Supervisor: Prof. W. Ketterle.

Thursday, June 7, 2007 1:30PM - 3:30PM –
Session J2 Focus Session: Quantum Monte Carlo Calculations and Other Numerical Simulations of Cold Gases

1:30PM J2.00001 Quantum Monte Carlo (QMC) Methods for strongly correlated Bose and Fermi Systems, NANDINI TRIVEDI, The Ohio State University — I will give two examples where the fluctuations probed by QMC highlight the novel physics of strongly correlated systems. In the first example of bosons in optical lattices, we find in addition to the sound mode, evidence for extra gapped modes in the correlated superfluid phase [1]. We also calculate the effect of thermal and quantum fluctuations, including vortices, on the superfluid density and condensate fraction and compare with recent experiments in optical lattices [2]. In the second example, we calculate the pairing and superfluid properties of a dilute gas of fermions in 3-dimensions with attractive interactions tuned to the unitarity point [3]. From the growth of the density correlations for unequal spins, we identify the pseudogap crossover temperature scale $T^* \approx 0.7E_F$ below which pairing correlations develop. The pseudogap phase is characterised by the temperature dependence of spin susceptibility and compressibility. We estimate the critical temperature for condensation $T_c \approx 0.24E_F$ from a finite size scaling analysis of the superfluid density.

1C. Menotti and N. Trivedi, preprint.
3V. Akkineni, N. Trivedi, D.M. Ceperley, cond-mat/0608154.

2:06PM J2.00002 Variance minimization variational Monte Carlo method1, BO GAO, IMRAN KHAN, University of Toledo — We present a variational Monte Carlo (VMC) method that works equally well for the ground and the excited states of a quantum system. The method is based on the minimization of the variance of energy, as opposed to the energy itself in standard methods. As a test, it is applied to the investigation of the universal spectrum at the van der Waals length scale for two identical Bose atoms in a symmetric harmonic trap, with results compared to the basically exact results obtained from a multiscale quantum-defect theory. Results for trapped few-atom system will also be presented.

1Supported by NSF
2Y. Chen and B. Gao, cond-mat/0701384.

2:18PM J2.00003 Thermodynamic properties of the three-dimensional Bose-Hubbard model1, BARBARA CAPOGROSSO-SANSONE, EVGENY KOZIK, NIKOLAY PROKOF’EV, BORIS SVISTUNOV, Department of Physics, University of Massachusetts, Amherst — We have studied the thermodynamics of the three dimensional Bose-Hubbard model by means of exact quantum Monte Carlo simulations. We present accurate thermodynamic curves, including those for entropy and specific heat, for the homogeneous and inhomogeneous system. We also present numerical data for the on site number statistics and compare numerical curves to experimental ones, using temperature as the only free parameter. Our data can serve as a basis for accurate experimental thermometry and a guide for appropriate initial conditions if one attempts to use interacting bosons in quantum information processing.

1Work supported by the National Science Foundation Grant No. PHY-0426881

2:30PM J2.00004 2D Self-Assembled Crystals with Polar Molecules, GUIDO PUPILLO, Austrian Academy of Sciences — We discuss the possibility to control the strength and design the shape of the long-range part of the interaction potentials of bosonic polar molecules using static and microwave fields. The dressing of rotational excitations combined with low dimensional trapping provides novel tools to engineer strongly correlated quantum phases, which we study utilizing recently developed quantum Monte Carlo techniques. As an example, we show that intermolecular dipole-dipole interactions can drive the system from a superfluid to a self-assembled crystalline phase, which has never been observed so far with cold molecular or atomic gases.
with pseudo-states methods provide a check for the different distorted wave methods. We also plan to present ionization cross section results for $B^+V^-$ cross-sections near their thresholds, which is not found in an all

JULIAN BERENGUT, STUART LOCH, MICHAEL PINDZOLA, Auburn University, CONNOR BALLANCE, DON GRIFFIN, Rollins College, FL — Electron-polarization is essential for precision results. Results for the phase shifts, obtained in the present hybrid formalism, are rigorous lower bounds to the exact phase

is general enough to include the target distortions (polarization) in the presence of the incident electron, except for scattering lengths for which inclusion of orbitals and they are close to the phase shifts calculated by Bhatia and Temkin [Phys. Rev. A 64, 032709-1 (2001)]. This indicates that the correlation function of Hylleraas type. It is found that the phase shifts are not significantly affected by the modification of the target function by a method similar to the polarized correlation effects are very important.

formulation and the new sets of codes can be used to study electron scattering / photoionization in heavy atomic systems where relativistic and electron TCE searches for an optimal implementation of these tensor contraction expressions and generates high performance FORTRAN code for CCT. We will also

Theoretical formulation of CCRM and the computational implementation using the high level Mathematica style language compiler known as Tensor Contraction (CCT), the size extensive and one of the most accurate many body theories which is equivalant to an all-order many-body perturbation theory (MBPT). General as well. We will give an outline of the coupled-cluster R-matrix (CCRM) theory to incorporate the effect of electron correlation through coupled-cluster theory

accurate results, particularly for resonances in the near-threshold region. In addition, a hybrid method, combining a second-order distorted-wave method for a fast ionizing projectile with a convergent $R$-matrix with pseudo-states approach for the initial bound state and the ejected electron [4], has been very successful in treating ionization of heavy noble gases [5] and simultaneous ionization-excitation of He [6]. Examples will be presented at the conference.

One of Complex Atoms

accurate results, particularly for resonances in the near-threshold region. In addition, a hybrid method, combining a second-order distorted-wave method for a fast ionizing projectile with a convergent $R$-matrix with pseudo-states approach for the initial bound state and the ejected electron [4], has been very successful in treating ionization of heavy noble gases [5] and simultaneous ionization-excitation of He [6]. Examples will be presented at the conference.

This work was supported in part by NSF.

Thursday, June 7, 2007 1:30PM - 3:54PM –
Session J3 Focus Session: Electron-Atom Collisions TELUS Convention Centre Glen 201-203

1:30PM J3.00001 High-Precision Calculations for Electron-Impact Excitation and Ionization of Complex Atoms1, KLAUS BARTSCHAT, Drake University — While electron collisions with the valence electrons of light (quasi-)one- and (quasi-)two-electron atoms, such as H, He, the alkalis, and the alkali-earth elements, can now be handled very accurately by various theoretical methods (convergent close-coupling, $R$-matrix with pseudo-states, exterior complex scaling, or time-dependent close-coupling), the situation is much less satisfactory for complex open-shell targets such as Mo or Fe, or for collisions involving excitation or ionization of inner shells in the heavy noble gases. In recent years, our group has further developed an alternative version of the $R$-matrix (close-coupling) method, using a $B$-spline basis with non-orthogonal sets of term-dependent orbitals [1-3]. This method allows us to generate target descriptions of unprecedented accuracy in collision calculations, which turn out to be of critical importance for accurate results, particularly for resonances in the near-threshold region. In addition, a hybrid method, combining a second-order distorted-wave method for a fast ionizing projectile with a convergent $R$-matrix with pseudo-states approach for the initial bound state and the ejected electron [4], has been very successful in treating ionization of heavy noble gases [5] and simultaneous ionization-excitation of He [6]. Examples will be presented at the conference.


1Major contributions to the work presented in this talk were made by Oleg Zatsarinny. This work is supported by the United States National Science Foundation under grants PHY-0244470 and PHY-0555226.

2:06PM J3.00002 Correlated R-matrix theory of electron scattering: A coupled-cluster approach1, CHIRANJIB SUR, ANIL PRADHAN, P. SADAYAPPAN, The Ohio State University — Study of electron scattering from heavy atoms/ions not only demands high speed computing machines but also improved theoretical descriptions of the relativistic and correlation effects for the target atoms/ions as well. We will give an outline of the coupled-cluster R-matrix (CCRM) theory to incorporate the effect of electron correlation through coupled-cluster theory (CCT), the size extensive and one of the most accurate many body theories which is equivalent to an all-order many-body perturbation theory (MBPT). General theoretical formulation of CCRM and the computational implementation using the high level Mathematica style language compiler known as Tensor Contraction Engine (TCE) will be presented. Electronic structure calculations using CCT involve large collections of tensor contractions (generalized matrix multiplications). TCE searches for an optimal implementation of these tensor contraction expressions and generates high performance FORTRAN code for CCT. We will also comment on the interfacing of TCE generated code with the Breit-Pauli R-matrix code to make a next generation CCRM software package. This theoretical formulation and the new sets of codes can be used to study electron scattering / photoionization in heavy atomic systems where relativistic and electron correlation effects are very important.

1Partially supported by NSF and Ohio State University.

2:18PM J3.00003 Hybrid Theory of Electron-Hydrogen Scattering, ANAND BHATIA, NASA/Goddard Space Flight Center — I report on a study of electron-hydrogen scattering, using a combination of a modified method of polarized orbitals and the optical potential formalism which does not require projection operators. The calculation is restricted to S-wave scattering in the elastic region, where the correlation functions are of Hylleraas type. It is found that the phase shifts are not significantly affected by the modification of the target function by a method similar to the polarized orbitals and they are close to the phase shifts calculated by Bhatia and Temkin [Phys. Rev. A 64, 032709-1 (2001)]. This indicates that the correlation function is general enough to include the target distortions (polarization) in the presence of the incident electron, except for scattering lengths for which inclusion of polarization is essential for precision results. Results for the phase shifts, obtained in the present hybrid formalism, are rigorous lower bounds to the exact phase shifts.

2:30PM J3.00004 Electron-impact ionization of atomic ions in the B isonuclear sequence, JULIAN BERENGUT, STUART LOCH, MICHAEL PINDZOLA, Auburn University, CONNOR BALLANCE, DON GRIFFIN, Rollins College, FL — Electron-impact ionization cross sections for several atomic ions in the B isonuclear sequence are calculated using both perturbative and non-perturbative theoretical methods. A distorted wave calculation in a mixed $1s^{-1}$ potential for neutral B exhibits a large shape resonance in the 2s and 2p subshell ionization cross-sections near their thresholds, which is not found in an all $1s^{-1}$ potential distorted-wave calculation. The time-dependent close-coupling and $R$-matrix with pseudo-states methods provide a check for the different distorted wave methods. We also plan to present ionization cross section results for $B^9+, B^{10+},$ and $B^{11+}$.
Recent Progress in Electron-Atom Scattering

JULIAN LOWER, Centre for Antimatter Matter Studies, RSPHYSE, Australian National University, Canberra, ACT, 0200, Australia — The application of multi-parameter data collection techniques to electron-atom collision-experiments allows statistically significant results to be obtained for weak physical effects [1]. In addition to improved count rates, if the spin projection of the primary electron is determined, the roles of electron exchange and relativity in the scattering process can be highlighted. Examples of recent measurements from our laboratories will be discussed in the context of work from other groups. These will include benchmark measurements on the electronic excitation of helium employing the time-of-flight technique [2]. The technique allows inelastic cross sections to be accurately placed on an absolute scale by normalization to well-established elastic cross sections. Measurements on the (e,2e) ionization/excitation of helium through the application of energy-dispersive toroidal-analyzers will also be discussed [3]. The results provide a stringent test to theory and indicate the strengths and limitations of state-of-the art calculations in describing the Coulomb 4-body problem. Finally I will describe results from (e,2e) measurements on argon [4] and xenon [5] targets performed with spin polarized electrons which probe the many-body nature of electron exchange-scattering.


Support through the Australian Research Council is gratefully acknowledged.

Multi-Dimensional Momentum Images of Electron-Impact Induced Ionization of Atoms and Molecules

J. ULLRICH, A. DORN, M. DUERR, N. HAAG, CH. DIMOPOULOU, Max-Planck-Institut für Kernphysik, 69117 Saupfercheckweg 1, Heidelberg, Germany — A dedicated Reaction Microscope was developed that enables to measure the complete momentum vectors of electrons and ions emitted in ionizing collisions of electrons with atoms and molecules. Realizing a special geometrical design we are able to access very low projectile energies, to detect the scattered projectile electron in addition to all target fragments, and to observe ionic fragments from molecular dissociation. Selected recent results will be highlighted: For single ionization of He by 1 keV and 105 eV electrons the 3D electron emission patterns show structures outside the scattering plane, so far not been observed in conventional experiments. Studies for double ionization of He close to the threshold provide detailed insight into the behaviour of four strongly interacting continuum particles. Finally, pioneering (e,2e) results for single ionization of oriented H2 molecules are presented.


Out-of-plane (e, 2e) experiments on an autoionizing resonance using 488 eV incident energy electrons. 1. B.A. DEHARAK, N.L.S. MARTIN, University of Kentucky — Over the past several years there have been a variety of kinematically complete experiments with both coplanar and out-of-plane geometry involving charged particle impact ionization of a variety of atomic targets. Examples where data were obtained using COLTRIMS spectrometers include single ionization of helium by ions and electrons. An example where data were obtained using a more traditional spectrometer involved single ionization of magnesium by electron impact. Each of these studies has shown that while theoretical descriptions of coplanar experiments tend to be very good, there are large discrepancies in the description of out-of-plane experiments, providing ample motivation for further experimental studies. We have begun to perform kinematically complete out-of-plane experiments on helium using a traditional (e,2e) spectrometer modified for out-of-plane operation. These experiments cover all 2π radians of a plane that includes the momentum transfer direction and is perpendicular to the scattering plane. An overview of the apparatus will be presented as will preliminary results showing the angular distributions for direct ionization and autoionization via He 3s/2p P 1.

This work was supported by the United States National Science Foundation under Grant No. PHY-0555541.

Electron Scattering From Laser Excited Ba and Yb Atoms

PETER ZETNER, JEFF HEIN, University of Manitoba — Inelastic and elastic electron scattering out of the excited states of Ba and Yb has been studied at low collision energies. We present measurements (at 10 eV and 20 eV collision energies) of differential cross sections and orientation parameters for elastic scattering out of the 6 1P, and 5 D levels of Ba and for inelastic scattering out of the 6 3P, level of Yb to higher lying 3D and 5 S levels. Collision studies are carried out using a momentum selected incident electron beam with momentum resolved scattered electron detection and excited atomic target populations generated by resonant laser radiation. To a good approximation, Ba and Yb are heavy two-electron systems comprised of, approximately inert cores ([Xe] for Ba and [Xe]4f 39 for Yb) with two-electron 6s 2 valence configurations (in the ground state). Theoretical determinations of low-energy electron scattering parameters for these atoms, based on convergent close coupling and first order perturbative formalisms, have met with success in many cases. Such calculations have been applied to inelastic scattering from 6S, 5D and 6P target states in Ba and the 6S ground state in Yb (refs 1,2). Extension of previous experimental investigations to the new scattering processes described in this work will further test the efficacy of available theoretical methods. 1. I. Bray et al. J.Phys.B:At.Mol.Opt.Phys. 35 R117 (2002) 2. B Predojevic et al. J. Phys. B: At. Mol. Opt. Phys. 38 2489 (2003)

Thursday, June 7, 2007 1:30PM - 3:54PM
Session J4 Cold Atoms in Optical Lattices and Double-Well Potentials

Cold Atoms in Optical Lattices and Double-Well Potentials

JULIAN LOWER, Centre for Antimatter Matter Studies, RSPHYSE, Australian National University, Canberra, ACT, 0200, Australia

Quantum Noise Interferometry: Phase transitions and entanglement in cold atoms in optical lattices

INDUBALU SATIJA, George Mason University, ANA MARIA REY, ITAMP, Harvard -Smithsonian Center of Astrophysics, CHARLES CLARK, NIST — “Intensity interferometry,” known as Hanbury-Brown Twiss (HBT) interferometry where quantum noise is used as a tool to detect quantum correlations is emerging as a very effective tool in the study of various complexities of strongly correlated systems. The technique is based on “bunching” effect of bosons and corresponding “Anti-bunching” of fermions due to the underlying quantum statistics. In cold atomic systems HBT can be done by detailed analysis of time of flight images of the expanded atomic cloud. We demonstrate the importance of the intrinsic quantum noise in the study of quantum phase transitions such as the Anderson-type transition in strongly interacting bosons, and the magnetic phase transition in quantum Ising models. We argue that noise interferometry provides a new order parameter for characterizing quantum phase transitions and may be viewed as a measure of quantum entanglement.

Stability of two-component and spinor condensates in optical lattices

ZACHARY DUTTON, Naval Research Lab, JANNE RÜOSTEKOSKI, University of Southampton, School of Applied Mathematics — We carry out an analysis of two-component (spin 1/2) and spinor (spin 1) BEC's in optical lattices. Using a Bogoliubov approach, we derive analytic conditions for the stability of these systems for both moving and stationary condensates in terms of the BEC interaction parameters and lattice kinetic energy. Both energy instabilities and dynamical instability conditions are derived and our results include both positive and negative interaction strengths. In both the two-component and spinor cases, we find the stability phase diagram closely reflects the free space case.

1:42PM J4.00002
1:54PM J4.00003 Phase diagrams of the Bose-Fermi-Hubbard-Model: Analytical and numerical studies, ALEXANDER MERING, MICHAEL FLEISCHHAUER, Technical University of Kaiserslautern — We present calculations for the Bose-Fermi-Hubbard model both in the limit of vanishing fermionic hopping (infinity large mass) and large fermionic hopping (vanishing mass). In the first case, a detailed study of the fermionic ground state which minimizes the energy for the bosons allows a straight forward prediction of the phase diagram in terms of the pure Bose-Hubbard model. The resulting incompressible phases can be classified and Bose glass like phases are predicted. In the second case, the fermions act as a reservoir to the bosons and an effective hamiltonian can be derived. This hamiltonian corresponds to an extended Bose-Hubbard model with long range oscillatory density-density interactions that depend on the fermionic filling and lead e.g. to the formation of density waves. In both cases, analytic results are given and compared to numerical calculations obtained using DMRG and exact diagonalization methods.

2:06PM J4.00004 Turning back time in the optical lattice: using the Loschmidt echo as a sensor, FERNANDO CUCCHIETTI, Los Alamos National Labs — I will show how to perform a time reversal of the dynamics of cold bosonic atoms in an optical lattice. The time reversal creates a Loschmidt echo and is obtained by applying a linear phase imprint on the lattice and a change in magnetic field to tune the boson-boson scattering length through a Feshbach resonance. I will discuss how to use the echo as a sensor to measure intensities of external potentials (e.g. gravity, magnetic fields, etc.), and also interesting quantities such as the fidelity of the quantum simulation of the Bose-Hubbard Hamiltonian, and the critical point and exponents of the superfluid-insulator quantum phase transition in this model.

2:18PM J4.00005 Thermally activated defects in a two-dimensional lattice of Bose-Einstein condensates, VOLKER SCHWEIKHARD, SHIKHUANG TUNG, ERIC CORNELL, JILA, NIST and Department of Physics, University of Colorado, Boulder, CO 80309-0440, USA — We present a study of thermally activated phase defects in a two-dimensional (2d) Josephson junction array of Bose-Einstein condensates (BECs), created by adiabatically loading a pre-formed BEC into a 2d optical lattice. Each lattice site contains thousands of condensed atoms, so that the phase of each condensate is well-defined. Nearest-neighbor tunneling provides a Josephson coupling \( J \) which acts to keep the condensates' relative phases locked. A cloud of uncondensed atoms, in thermal equilibrium with the condensate array at a temperature \( T \), on the other hand induces thermal fluctuations of the condensate phases. By varying the optical lattice depth we tune the Josephson coupling in the vicinity of the thermal energy, and thus induce a crossover between a phase-locked array for \( J > T \) and a disordered array for \( J < T \). We observe phase defects by turning down the optical lattice on a timescale fast for the defects to heal, thus converting them to vortices and solitons in the reconnected condensate. The physics of this system is closely related to the Kosterlitz-Thouless transition observed in 2d superfluids and superconducting Josephson junction arrays.

1: Funding: NSF and NIST

2:30PM J4.00006 Breakdown of superfluid flow in a moving lattice, JONGCHUL MUN, PATRICK M. MEDLEY, DAVID A. HUCUL, DAVID M. WELD, DAVID E. PRITCHARD, WOLFGANG KETTERLE, MIT-Harvard Center for Ultracold Atoms, Research Laboratory of Electronics, Massachusetts Institute of Technology — The stability of superfluid currents in strongly interacting ultracold bosons was studied using a moving optical lattice. The critical momentum for a stable current was found to vary continuously from 0.5 recoil momentum in a weakly interacting superfluid (SF) to zero in the Mott insulator (MI) phase. This critical momentum was measured at various lattice depths, and the phase diagram was obtained. This measurement also enabled us to precisely determine the critical lattice depth for the SF-MI phase transition. The critical lattice depth was measured to be 13.5 recoil energy for a three-dimensional gas. When a one-dimensional gas was loaded into a moving optical lattice, a broadening of the transition between stable and unstable phases was observed.

2:42PM J4.00007 Superfluidity of Feshbach resonant atoms in an optical lattice, JUHA JAVANAINEN, TUN WANG, SUSANNE YELIN, U of Connecticut — We study atomic and molecular currents in a one-dimensional optical ring lattice for a Fermi gas in the vicinity of a Feshbach resonance by direct numerical diagonalization of small model systems. A rotational counterpart of flux quantization is used to demonstrate that a fraction of the current is carried by particles with twice the mass of an atom, which suggests pairing and superfluidity.

2:54PM J4.00008 Preparing Fermions in an Optical Lattice at Ultra-Low Temperature, J.R. WILLIAMS, R. STITES, J.H. HUCKANS, E.L. HAZLETT, K.M. O’HARA, Penn State University — Fermionic atoms confined in an optical lattice provide an exciting opportunity for the quantum simulation of iconic models of condensed matter physics. The 2D Hubbard model, for example, which purports to describe high-temperature superconductivity in the cuprates, can be experimentally realized. Exploration of the most interesting phases (e.g. anti-ferromagnetism or d-wave superfluidity), however, will require the attainment of extremely low temperatures, or equivalently, near-zero entropy. We present a preparation method in which a cold, spin-polarized gas of fermionic atoms with peak atomic density greater than that of the lattice site density is initially loaded into a deep 3D cubic optical lattice. The lowest band of the lattice is fully occupied, while the second band is only partially filled. Selective removal of atoms in the second band is accomplished by intensity modulation of the lattice beams which promotes atoms to a higher-lying band, from where they are allowed to escape the trapping region. The atoms that remain completely fill the lowest band and are at an extremely low temperature. We will discuss theoretical limitations on the achievable temperature and our experimental progress.

3:06PM J4.00009 Correlated dynamics of atom pairs in double well potentials, SIMON FÖLLING, PATRICK CHEINET, STEFAN TROTZKY, ARTUR WIDERA, MICHAEL FELD, Johannes Gutenberg-Universit"at Mainz, TORBEN MÜLLER, ETH Zuerich, IMMANUEL BLOCH, Johannes Gutenberg-Universit"at Mainz — The interplay between atom-atom interaction and tunneling governs the dynamics of many strongly correlated systems of ultracold atoms. The most elementary realization of such a system is a set of two potential wells coupled via tunneling and occupied by two interacting atoms. By superposing the periodic potentials of two standing light waves with a periodicity of 382.5nm and 765nm, respectively, we create a one-dimensional array of double well potentials for atoms with adjustable tunnel coupling and energy offset. Additional standing waves on the two orthogonal axes provide axial confinement, creating a three-dimensional array of up to \( 10^6 \) double wells occupied by one or two \(^{87}\text{Rb} \) atoms each. Loading only one side of each double well before enabling the tunneling, we can directly observe the dynamics of single atoms as well as of atom pairs. Since the ratio of the tunneling matrix element \( J \) and the on-site repulsive interaction \( U \) between two atoms can be modified in a wide range, the crossover from a tunneling- to an interaction-dominated regime can be observed. Here, the independent motion of two atoms changes to a correlated tunnel process of the pairs.
3:18PM J4.00010 Phase Coherence of Schrödinger Cat Sates in Gaseous BECs \(^1\). WILLIAM REINHARDT, University of Washington, Seattle — A quantum state diffusion (QSD) numerical study, initially carried out in the simple Bose-Hubbard model, of the stability of both the creation and stability of macroscopic superposition states of gaseous Bose condensates in double well traps is reported. It is assumed that observations are made in the far-detuned quantum non-demolition regime, and that de-phasing dominates particle loss. Within the framework of these assumptions, which avoids consideration of highly pedigreed cats, we present the results of a phase space analysis of QSD, with surprising results. Presence of continuous, but far-detuned, observation destabilizes the formation of cats following pi-phase imprinting of the part of the condensate in one of the wells, but in a surprisingly predictable manner, suggesting methods for at least partially negating its influence. Further, once macroscopic superposition states are formed, there are parameter regimes where simple single shot observation of the density profiles, and in some cases even continuous monitoring, of even quite extreme macroscopic superpositions has little effect on their continuing stability.

\(^1\)Supported in part by the US NSF.

3:30PM J4.00011 Exploring the phase diagram of a double-well optical lattice, N. LUNDBLAD, P. LEE, B. BROWN, J. SEBBY-STRABLEY, J.V. PORTO, I.B. SPIELMAN, W.D. PHILLIPS, National Institute of Standards and Technology — Recent work in our group has demonstrated the creation and utility of a double-well optical lattice, consisting of a three-dimensional array of dynamically deformable lattice sites spaced in a few microns and they with variable potential barriers between them. Here, we present lifetimes from an initially Bose-Condensed sample of \(^{87}\)Rb atoms. The various lattice parameters can be adjusted so as to create a stack of independent 2D lattices, or, in the sense of the so-called ‘two-leg ladder,’ an array of chained double wells. We present preliminary investigations into the phase diagram of this system, which has been predicted to exhibit novel transitions between a half-filling/unit-filling Mott insulator and the superfluid phase as the chain couplings are varied.

3:42PM J4.00012 Probing atomic state coherence with a double-well optical lattice, PHILIP JOHNSON, American University, JENNIFER SEBBY-STRABLEY, EITE TIESINGA, TREY PORTO, CARL WILLIAMS, NIST, Gaithersburg — I will describe the theory of using the double-well optical lattice as an atom beam splitter, focusing on its ability to probe both inter-well and intra-well coherences. I will also discuss interesting effects such as the collapse-and-revival of first-order coherence occurring at twice the on-site interaction energy (U), the role of the double well tilt, and adiabaticity requirements. We have recently implemented an atom interferometer based upon these ideas and seen clear evidence for the effects discussed above.

Thursday, June 7, 2007 1:30PM - 3:54PM –
Session J5 Cavity QED and Quantum Control TELUS Convention Centre Glen 205

1:30PM J5.00001 Blue trapping and dispersive observation of single atoms. , T. PUPPE, I. SCHUSTER, A. GROTHE, A. KUBANEK, K. MURR, P.W.H. PINKSE, G. REMPE, Max-Planck Institute for Quantumoptics — A single atom strongly coupled to a high-finesse cavity constitutes a fundamental quantum system of matter-light interaction. An established tool to localize an atom in the cavity mode is the optical dipole trap. So far, only red-detuned dipole traps have been demonstrated in cavity QED. Since the atom is trapped in a region of high intensity, the AC-Stark effect shifts the atomic energy levels. We store single atoms in a blue-detuned intracavity dipole trap. Here, the Stark shift vanishes while the atom is strongly coupled to a cavity mode. Strong coupling and a Stark shift much smaller than the trap height is directly observed in the normal-mode spectroscopy. The blue trap allows us to explore the regime of dispersive atom-light interaction. As a practical application, we demonstrate that a single atom, can efficiently be detected while spontaneously scattering only a few photons. The realization of the blue intracavity dipole trap now allows measurements in cavity QED while preserving the free-space properties of the atom.

1:42PM J5.00002 Deterministic Loading of Single Atoms in an Optical Cavity, SOO KIM, KEVIN FORTIER, MICHAEL GIBBONS, MICHAEL CHAPMAN, Georgia Institute of Technology — To utilize a single atom as a qubit in cavity QED requires exquisite control over both the internal and external degrees of freedom of the atom. In our experiment, a single rubidium atom is captured in a high gradient MOT. The atom is loaded into a 1-D optical lattice and then transported 8 mm to a high finesse optical cavity. The atoms are stored and continuously observed in the cavity for up 10 s by employing a cavity-assisted cooling scheme. With submicron control of position of the atom, we have studied the spatial dependence of the atom-cavity coupling. We present our recent results and future prospects.

1:54PM J5.00003 An atom chip for studying interactions between atoms and metal surfaces , J.D. CARTER, O. CHERRY, Department of Physics and Astronomy, University of Waterloo, J.D.D. MARTIN, Department of Physics and Astronomy & Institute for Quantum Computing, University of Waterloo — Magnetic microtraps (atom chips) typically use \(\mu\)m scale current-carrying wires on a substrate to confine cold atoms in magnetic field minima. The high field gradients achievable in such devices can be used to create small clouds of atoms at well-defined (and variable) distances from the surface of a chip. In situ excitation of the trapped atoms to Rydberg states can be conveniently used to investigate interactions between Rydberg atoms and the surface of the chip, without the complication of atomic motion inherent in experiments using atomic beams. However, stray electric fields from the current-carrying wires make Rydberg excitation problematic. To overcome this problem, we have fabricated a chip with an electrostatic shield over the wires. With submicron control of position of the atom, we have studied the spatial dependence of the atom-cavity coupling. We present our recent results and future prospects.

2:06PM J5.00004 ABSTRACT WITHDRAWN

2:18PM J5.00005 Nonlinear Optics of Ultracold Atoms in an Optical Cavity. , KATER MURCH, UC Berkeley, KEVIN MOORE, SUBHADEEP GUPTA, DAN STAMPER-KURN — We report observations of non-linear optical phenomena in an ultracold atomic gas in a Fabry-Perot cavity in the single atom strong coupling regime. Up to \(5 \times 10^{14}\) \(^{87}\)Rb atoms are trapped at the antinodes of an in-cavity far-off resonance optical standing wave. We have observed significant Kerr non-linearity and dispersive optical bistability in the transmission of a probe beam through the cavity at our lowest detectable intensities corresponding to \(10^{-2}\) photons in the cavity. The non-linear index of refraction responsible for these effects arises from the collective motion of atoms in the combined potential of the trap and probe.

2:30PM J5.00006 Dipole potential in a cavity: Bistable or not? , DOMINIC MEISER, JILA — The motion of an atom in a far red detuned light field inside a resonantly driven cavity has surprising and counter intuitive features because atoms and cavity field comprise an open quantum system exchanging energy and momentum with the environment. A dilemma arising in this context is whether the atom is attracted to the antinodes of the field where the derivative of the intensity with respect to atomic position vanishes or to some point away from the anti-node where it tunes the cavity less out of resonance such that the intensity at its location is maximum. We study this problem using a microscopic model that avoids the ad-hoc introduction of semiclassical force concepts. If the trapping is provided by few photons in the strong coupling regime, we find that the atom’s wavefunction collapses near resonant points away from the field antinodes due to measurements on the cavity field. In the limit of large photon numbers a generally non-conservative semiclassical force with an equilibrium point at the field antinode emerges.
In general we achieve yields (fidelity of the actual state relative to the target state) in the range \(\sim 85\%\), limited mostly by errors in the control fields. Partly this is accomplished by introducing a weak, quasi-cw diode laser, nearly resonant with the Rb(5p) \(\rightarrow\) Rb(4d) transition. However, an important component in switching from Rb\(^+\) to Rb\(^0\) production is shaping the ultra-fast pulse in the frequency and phase domains, putting “notches” in the beam at crucial wavelengths and adjusting the “chirp” of the pulse. For example, removing wavelengths near the D1 and Rb (5p) \(\rightarrow\) Rb(5d) transitions reduces Rb\(^+\) production by nearly two orders of magnitude. A detailed discussion of these and related results will be given.

1Supported by the U.S. Department of Energy.

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**2:42PM J5.00007 Coherent anti-Stokes Raman scattering microscopy in a microcavity**, MICHELE MARROCCO, ENEA — The combination of nonlinear spectroscopy and cavity QED is a stimulating field of research [see, for example, S. M. Spillane et al., Nature 415, 621 (2002)]. In this work, coherent anti-Stokes Raman scattering (CARS) taking place within a microcavity with parallel mirrors, is studied. The interest stems from the fact that CARS is a powerful nonlinear spectroscopic technique, particularly useful in imaging of microscopic samples [A. Zumbusch et al., Phys. Rev. Lett. 82, 4142 (1999)]. The theory of CARS microscopy applied to a sample placed within the microcavity is developed and the calculated CARS power in comparison with its free-space value shows the characteristic oscillation between inhibition and enhancement. If \(d\) and \(\lambda\) indicate the cavity apertures, instead, reveal weaker cavity effects as a consequence of the larger collection efficiency.

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**2:54PM J5.00008 Coherent Control of Molecular Ion Production in Cold Rb Vapor**, M.L. TRACHY, V. VESHPADIZDE, M.H. SHAH, H.U. JANG, B.D. DEPAOLA, Kansas State University — When Rb vapor is exposed to pulses of light from an ultra-fast laser having a central wavelength of about 800 nm, the result is a very large number of atomic Rb ions. This is because, within the bandwidth of the laser pulse, resonant three-photon ionization takes place along the ladder Rb(5s) \(\rightarrow\) Rb (5p) \(\rightarrow\) Rb(5d) \(\rightarrow\) Rb\(^+\). The first transition is at 780 nm, the second is at 776 nm, and the third is anything shorter than 1252 nm. Virtually all molecular ions are formed in the interaction of the optical pulse with the Rb vapor. In a series of experiments we show that this natural trend can be reversed, with greatly reduced Rb\(^+\) production and greatly increased Rb\(^0\) production. Partly this is accomplished by introducing a weak, quasi-cw diode laser, nearly resonant with the Rb(5p) \(\rightarrow\) Rb(4d) transition. However, an important component in switching from Rb\(^+\) to Rb\(^0\) production is shaping the ultra-fast pulse in the frequency and phase domains, putting “notches” in the beam at crucial wavelengths and adjusting the “chirp” of the pulse. For example, removing wavelengths near the D1 and Rb (5p) \(\rightarrow\) Rb(5d) transitions reduces Rb\(^+\) production by nearly two orders of magnitude. A detailed discussion of these and related results will be given.

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**3:06PM J5.00009 Circuit quanta transducers for quantum electromechanical systems**, GERARD MILBURN, THE UNIVERSITY OF QUEENSLAND, HSI-SHENG GOAN, NATIONAL TAIWAN UNIVERSITY, LOUISE KETTLE, MATTHEW WOOLEY, THE UNIVERSITY OF QUEENSLAND — We consider a very high frequency nano-mechanical oscillator coupled to a superconducting co-planar microwave resonator. The microwave cavity is modeled as a single mode cavity coupled to the nano-mechanical oscillator displacement. In this configuration the microwave cavity acts as a transducer for the motion of the nano-mechanical oscillator. If the coupling is strong the system may exhibit sub/harmonic generation in analogy to optical second order nonlinear optics. We also show how the bifurcation of the steady state to limit cycle dynamics in this system could be used as a bifurcation amplifier for readout of a single solid state qubit. We calculate the noise on the limit cycle and assess how well it can function as a single qubit readout device. We also consider the case of weak coupling with parametric driving of the nanomechanical resonator. In this case mechanical squeezing occurs and may be detected in the microwave field. We calculate the observed noise power spectrum for the microwave field with realistic experimental parameters.

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**3:18PM J5.00010 Synthesis of Arbitrary States of Large Atomic Spins by Quantum Control**, SOUMA CHAUDHURY, UNIVERSITY OF ARIZONA, TUCSON, SETH MERKEL, TOBIAS HERR, IVAN DEUTSCH, POUL JESSEN — A spin 1/2 system is fully controllable if an observable and a Hamiltonian can be found which generate in time the desired observable. A single spin is such a system. We consider a large collection of spin-1/2 atoms aligned in a linear chain and apply quantum control methods to manipulate the collective spin state. The advantage of using a collective spin is that the number of atoms can be increased without significantly changing the timescale of the required interactions. Here, we show that a collection of spin-1/2 atoms can be used to create a collective spin with a higher effective spin quantum number. The collective spin can then be prepared in desired states. We consider a collection of \(N\) spin-1/2 atoms with an arbitrary Hamiltonian. We show how to use dynamical control to manipulate the collective spin state. The collective system can be prepared in arbitrary states and can be used for quantum information processing.

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**3:30PM J5.00011 Long-range interactions and many-body effects in a cold Rydberg gas**, ROBIN CÔTÉ, JOVICA STANOJEVIC, University of Connecticut — In recent years, the unique combination of properties of ultracold Rydberg atoms, such as long radiative lifetimes or strong long-range interactions, has led to proposals for using them to implement fast quantum gates. Here, we explore the behavior of macroscopic atomic samples where laser excitation of ultracold atoms to high-lying Rydberg states is locally blockaded due to the strong van der Waals interactions between Rydberg atoms. We discuss a mean-field model that defines local blockade domains and agrees well with experimental observations. In a \(N\)-atom mesoscopic sample under perfect blockade condition, the single excitation is described by a many-body Rabi frequency, \(\sin^2(\sqrt{N} \Omega_{12})\). Here, \(\Omega_{12}\) is the Rabi frequency for the motion of the nano-mechanical oscillator. If the coupling is strong the system may exhibit sub/harmonic generation in analogy to optical second order nonlinear optics. We also show how the bifurcation of the steady state to limit cycle dynamics in this system could be used as a bifurcation amplifier for readout of a single solid state qubit. We calculate the noise on the limit cycle and assess how well it can function as a single qubit readout device. We also consider the case of weak coupling with parametric driving of the nano-mechanical resonator. In this case mechanical squeezing occurs and may be detected in the microwave field. We calculate the observed noise power spectrum for the microwave field with realistic experimental parameters.

1Supported by NSF.

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**3:42PM J5.00012 Quantum electrodynamics of qubits**, IWO BIALYNICKI-BIRULA, TOMASZ SOWINSKI, Center for Theoretical Physics, Warsaw, Poland — Powerful methods of relativistic quantum electrodynamics are applied to the study of the interaction of qubits with the quantized electromagnetic field. These methods lead to a significant progress in the study of various properties of two-level systems. The application of the tools of relativistic QED to the description of two-level systems is made possible by a close analogy between the Dirac sea of filled negative-energy electron states and the occupied lower-energy state of a two-level system. Propagators, the S-matrix, and Feynman diagrams turn out to be particularly useful. Using these tools we profit from numerous simplifications in the calculations that made the Feynman-Schwinger-Dyson approach to QED so successful. Subjecting to these simplifications, the calculations of higher order corrections in perturbation theory become very simple. The integration over the intermediate energies can be performed in any order of perturbation theory by the standard method of residues. The analysis is carried out for two-level atoms and for spins. In particular, the polarizability of a two-level atom is calculated in the fourth-order of perturbation theory. This calculation is made simple by the analogy with the vacuum polarization in QED. Also, the treatment of nonlinear phenomena in two-level systems by analogy with their counterparts in QED is very successful.
1:30PM J6.00001 Intense field ionization of diatomic molecules in the tunneling region. 
ZI JIAN LONG, WING-KI LIU — There are two theoretical approaches to study the strong field ionization of molecules. One is based on a static picture in which the electron is considered to tunnel out through a potential barrier (ADK Theory [1]). In this approach the time dependence of laser field is taken into account by averaging the static ionization rate over time. A simple ionization formula can be obtained and it well predicts the experimental result in the tunneling region. Another theoretical approach is the time-dependent picture based on an S-matrix formalism. An essential feature of this approach is Strong Field Approximation (SFA). We expect that in the tunneling regime the SFA will give similar analytical expression as in the ADK theory. Much work has been done in the atomic case as described. Here we study the strong field ionization of simple diatomic molecules in which the electron's wave functions will be represented by linear combination of atomic orbitals (LCAO). We will consider the ionization rate in tunneling regime for diatomic molecules and investigate the interference effects between different atomic orbitals. We will compare our asymptotic formula with numerical calculation for simple systems.


1:42PM J6.00002 Direct time-resolved observation of molecular dynamics induced by extreme-ultraviolet photoionization. ARVINDER SANDHU, ETIENNE GAGNON, ARIEL PAUL, MARGARET MURNANE, HENRY KAPTEYN, JILA, University of Colorado and NIST, Boulder, Colorado 80309-0440, USA; PREDRAG RANITOVIC, C. LEWIS COCKE, J. R. Macdonald Laboratory, Kansas State University, Manhattan, Kansas 66506-2601, USA — Laser-generated high-order harmonics provide a source of extreme-ultraviolet radiation with unique capabilities for probing atomic and molecular dynamics. Here we present the first such studies by employing high harmonics in conjunction with coincident electron-ion 3D momentum imaging (COLTRIMS) technique. We generate femtosecond EUV pulses at ~ 42 eV photon energy by upconverting intense (~ 10^14 Wcm^-2) 25 fs laser pulses in an argon filled waveguide. Using this ultrashort EUV pulse as a pump, we launch D2, N2 and CO into highly excited states near the molecular double-ionization threshold. The dynamics of these highly excited states unfold along different channels, which are identified by electron-ion correlation. We generate high-order harmonics of intensity infrared fields, we delay the laser pulse and map the field-free alignment. We observe that the double ionization yield is significantly enhanced by the presence of an IR field in conjunction with the EUV pump. The kinetic energy release evolves as a function of delay time (internuclear distance), allowing us to map excited state dynamics.

1:54PM J6.00003 Electron Momentum Distributions from Strong-Field Ionization of Aligned Molecules. DANIEL COMTOIS, HEIDI BANDULET, INRS-EMT, DOMAGOJ PAVICIC, National Research Council, MORTIZ MECKEL, J.W. Goethe-Universitat, ANDRE STAUTDE, National Centre, DIRK ZEIDLER, Carl Zeiss SMT, REINHAUD DORNER, J.W. Goethe-Universitat, HENRI PEPIN, JEAN-CLAUDE KIEFFER, INRS-EMT, DAVID VILLENEUVE, PAUL CORKUM, National Research Council — Using a velocity map imaging electron spectrometer, we measured the velocity distribution of electrons produced by strong laser field ionization of aligned molecules. By taking the ratio of velocity distributions obtained for different molecular orientation distributions, we are able to isolate the modulations due to molecular alignment. The low momentum part of the distributions is populated by electrons that are directly emitted from the molecule without subsequent rescattering with the ion core. For these electrons, the modulations of the electron velocity distribution are observed solely along the axis perpendicular to the laser field. They are caused by the projection of the molecular orbital's wavefunction into the perpendicular momentum distribution of the ionized electron wavepacket. The high momentum part of the distributions is populated by electrons that have rescattered with the ion core. The modulations seen in the ratio of the velocity distributions for these electrons are believed to be due to diffraction of the electron wavepacket by its parent ion.

2:06PM J6.00004 Mapping the rapid time evolution of impulsively aligned deuterium molecules using intense few-cycle infrared laser pulses.1 JARLATH MCKENNA, CHRIS CALVERT, IAN WILLIAMS, Queens University Belfast, WILLIAM BRYAN, ELIZABETH ENGLISH, JOSEPH WOOD, ROY NEWELL, University College London, RICARDO TORRES, Imperial College London, EDMOND TURCU, Rutherford Appleton Laboratory — Short intense laser pulses have recently become a viable and efficient method of impulsively inducing alignment of molecules, ranging from simple diatomics to more exotic structures. Key to the widespread applicability of this technique is that the maxima and minima of alignment occur under field-free conditions at delayed periodic intervals corresponding to the quantum rotational revival of the system. In effect, the laser pulse creates a coherent superposition of the rotational states of the molecule which undergo a quantum dephasing and rephasing as it evolves in time. We present here an experiment where we use few-cycle infrared laser pulses to induce and map the ultrafast field-free alignment of deuterium molecules starting from a randomly distributed ensemble at room temperature. The results, including angular distribution measurements, are compared to theory which describes the experimental data to a high degree.

1Funding from EPSRC (UK) is gratefully acknowledged.

2:18PM J6.00005 Energy and angular structure in momentum space images of electrons ionized from aligned O2 and CO molecules by short, intense laser pulses.1 CHAKRA MAHARJAN, PREDRAG RANITOVIC, IRINA BOCHAROVA, DIPANWITA RAY, BEN GRAMKOW, IGOR LITVINYUK, C. LEWIS COCKE, Kansas State University — We have used COLTRIMS to measure momentum spectra of electrons generated by ionizing dynamically aligned molecules of O2 and CO. The ionization rates have recently become viable and efficient method of impulsively ionizing molecules, ranging from simple diatomics to more exotic structures. Key to the widespread applicability of this technique is that the maxima and minima of alignment occur under field-free conditions at delayed periodic intervals corresponding to the quantum rotational revival of the system. In effect, the laser pulse creates a coherent superposition of the rotational states of the molecule which undergo a quantum dephasing and rephasing as it evolves in time. We present here an experiment where we use few-cycle infrared laser pulses to induce and map the ultrafast field-free alignment of deuterium molecules starting from a randomly distributed ensemble at room temperature. The results, including angular distribution measurements, are compared to theory which describes the experimental data to a high degree.

1This work was supported by Chemical Sciences, Geosciences, and Biosciences Division, Office of Basic Energy Sciences.

2:30PM J6.00006 Few cycle (<10fs) intense laser-induced ionization and dissociation of simple diatomic molecules probed by coincidence 3D momentum imaging.2 A. MAX SAYLER, PENGQIAN WANG, JARLATH MCKENNA, FATIMA ANIS, BISHWANATH GAIRE, NORA G. JOHNSON, ELI PARKE, MAT LEONARD, KEVIN D. CARNES, B.D. ESRY, ITZIK BEN-ITZHAK, J.R. Macdonald Laboratory, Department of Physics, Kansas State University — Laser-induced ionization and dissociation of H2+, HD+, and D2+ by sub-10 fs 790 nm pulses with intensities up to 10^15 W/cm^2 have been studied using coincident 3D momentum imaging. Since the hydrogen molecular-ion (and its isotopes) is the simplest molecule, it provides an excellent testing ground for the strong-field dissociation of molecular ion in behavior in intense few-cycle laser pulses. The experimental findings are contrasted with both existing experimental studies of these molecular ions in longer laser pulses and theoretical calculations, which include all possible physical processes except ionization.

2Thanks to Professor Zenghu Chang for providing the intense laser beams and Dr. Charles Fehrenbach for his help with the ion beams. Work supported by the Chemical Sciences, Geosciences, and Biosciences Division, Office of Basic Energy Sciences.
We would like to acknowledge support from the NSF under Grant No. PHYS-0244658.
**K1.00001 QUANTUM INFORMATION: OPTICAL**

K1.00002 Decoherence of a driven quantum system interacting with environment through many degrees of freedom

1. ZHONGYUAN ZHOU, SHIH-I. CHU, Department of Chemistry, University of Kansas, Lawrence, KS 66045, SIYUAN HAN, Department of Physics and Astronomy, University of Kansas, Lawrence, KS 66045 — We present a comprehensive approach for the study of decoherence of an ac-field-driven multilevel quantum system interacting with environment through many degrees of freedom. In this approach, the system is described by a reduced density operator and the environment is characterized by a number of spectral densities. The reduced density operator is governed by a master equation in which the effect of ac fields and leakage to non-computational states are included. The approach is applied to investigate decoherence of a SQUID flux qubit with a two-dimensional (2D) potential coupled to environment through its control and readout circuits. The calculated relaxation time agrees well with experimental result when the potential is quasi one-dimensional (1D). Effects of the second degree of freedom, which is frozen in a quasi-1D system, on relaxation and decoherence times are examined systematically by varying circuit parameters.

K1.00003 Efficient NMR manipulation of single electron-nuclear spin registers

1. PAOLA CAPPELLARO, ITAMP, LIANG JIANG, MIKHAIL LUKIN, Department of Physics, Harvard University — Motivated by recent experiments with single nitrogen-vacancy centers in diamond, we consider a few-qubit quantum system composed of a single electron and proximal nuclear spins. Initialization and read-out of such a quantum register is accomplished optically via the electron spin. Due to the large hyperfine coupling, the nuclear spins can be addressed individually. We describe NMR-based techniques for efficient initialization and coherent manipulation of such registers composed of multiple nuclear spins. We analyze feasible performances and practical limitations of this approach in a realistic setting. This hybrid approach combines ideas from quantum optics, mesoscopic physics and NMR to yield a robust, potentially scalable quantum information system.

K1.00004 Scalable Quantum Networks based on Few-Qubit Registers

1. LIANG JIANG, Department of Physics, Harvard University, JACOB TAYLOR, Department of Physics, Massachusetts Institute of Technology, ANDERS SORENSEN, The Niels Bohr Institute, University of Copenhagen, MIKHAIL LUKIN, Department of Physics, Harvard University — We describe and analyze a hybrid approach to scalable quantum computation that is based on probabilistically connected optical network consisting of few-qubit quantum registers. We show that, in principle, two-qubit quantum registers, connected by probabilistic entanglement generation, suffice for scalable, deterministic quantum computation. We then show that with additional three qubits per register, robust non-local quantum operations can be implemented, even when state preparation, measurement, and entanglement generation all have limited fidelity. Finally, we discuss error thresholds relevant for scalability of our approach by mapping it to a general network error model.

K1.00005 Universal Control of Nuclear Spins via Anisotropic Hyperfine Interactions

1. JONATHAN S. HODES, JAMIE C. YANG, CHANDRASEKHAR RAMANATHAN, DAVID G. CORY, Massachusetts Institute of Technology — Nuclear spins are appealing as qubits in quantum information processing given their long coherence times; however these systems still require an efficient means of initial state preparation and state measurement. Many proposals rely on a localized electron spin coupled to the nuclear spins via the hyperfine interaction for aiding in initialization and read-out. When the hyperfine interaction between electron and nuclear spins has an anisotropic coupling, we describe how universal control over the combined subsystems can be attained by driving only the electron spin transitions. Building on the GRAPE method for quantum control, we propose a method for modulating solely the electron spin that allows for faster, more robust quantum operations on the nuclear spins than would be achieved by addressing the nuclear spins directly. We experimentally demonstrate these ideas in a test bed system of one $S=1/2$ electron spin and one $I=1/2$ nuclear spin and show that a universal set of gates can be achieved on this system. Also, we present preliminary results on our ability to polarize the combined system by controlling polarization transfer from the electron to the nuclear spin in the presence of electron spin relaxation.


K1.00006 Real Source Quantum Key Distribution Relays

1. GINA HOWARD, WOLFGANG TITTEL, BARRY C. SANDERS, IQIS University of Calgary — We have developed a model for relay-based quantum key distribution that incorporates multi-photon source events and dark counts at detectors. The model compares achievable quantum key distribution rates for configurations with different numbers of segments over a range of distances. Different photon source distributions and dark count rates are compared for given configurations to ascertain the impact of the source and detector imperfections on secure key rates.

K1.00007 Towards Fast Quantum Secured Communication

1. ITZEL LUCIO MARTINEZ, PHILIP CHAN, student, STEVE HOSIER, XIAOFAN MO, Postdoctoral position, WOLFGANG TITTEL, Associate professor — An ideal implementation of QKD would employ a perfect single photon source which is currently not available. The decoy state protocol uses faint laser pulses with different intensities that allows the two end points to eliminate cryptographic key data created from multi-photon pulses. The remaining cryptographic key data is obtained from single-photon pulses making it absolutely secure. The decoy state protocol increases the distance of transmission and the rate of secret key generation. In this poster we discuss the implementation of a decoy state protocol using polarization encoding in a standard telecommunication fibre Alice generates laser pulses which are then intensity modulated and attenuated to produce either signal or decoy states. Alice then uses phase modulators to create polarization states which she sends, via a fibre link, to Bob. Bob uses polarization beam splitters and single photon detectors to separate and measure the polarization states. The implementation of the decoy state protocol and the advances in single photon detectors expected in the next few years, will result in a significant increase in the achievable raw key rate. It is thus necessary to develop high speed solutions for the classical post-processing required for QKD. To this end, an FPGA implementation of low-density parity-check codes utilizing a set of precomputed codes is being investigated.

K1.00008 Production of Entangled Photon Pairs in Optical Fiber via Four-Wave Mixing

1. JOSHUA SLATER, AHDIYEH DELFAN, ALLISON RUBENOK, IQIS, University of Calgary, FÉLIX BUSSIÈRES, IQIS, University of Calgary; COPL, Polytechnique Montréal, NICOLAS GODBOUT, COPL, Polytechnique Montréal, WOLFGANG TITTEL, IQIS, University of Calgary — Building a quantum cryptography network with optical fiber is desirable as fiber is well understood and networks are already widespread. Transmitting through free-space is also desirable as it allows key distribution where optical fibers are not available. However, the absorption minima for these methods are at widely separated wavelengths: 1550 nm for fiber and around 800 nm for free-space. To create a hybrid network we are working towards teleporting quantum information from a photon suitable for fiber transmission to a photon suitable for free-space transmission. To achieve this, we require entangled photons at widely separated wavelengths, which are normally produced in non-linear crystals. Our research focuses on producing the entangled pair directly in optical fiber using four-wave mixing (FWM). We examined the possibility of using two pump lasers at widely separated wavelengths, whereas previous FWM photon pair source experiments have used a single pump laser. We present initial results of phase matching for feasible experimental setups.
K1.00009 Manipulation of Energy Gap of Thallium Quantum Dots, CHOONGYU HWANG, NAMDONG KIM, GEUNSIK LEE, SUNYOUNG SHIN, SANGHUN UHM, HYOSANG KIM, JAESAM KIM, JINWOOK CHUNG, Physics, POSTECH — We have characterized the electronic properties of thallium (Tl) quantum dot (QD) array using high-resolution electron-energy-loss spectroscopy, photoemission spectroscopy, and first-principle calculations. The surface with the QD’s exhibits a weakly semiconducting character with a band gap less than 0.23 eV in sharp contrast with previous scanning-tunneling spectroscopy observation [1]. We have observed the non-varying excitation energy of an interband transition in conflict with two kinds of binding energy shift with the variation of effective separation between the QD’s. We analyze the experimental findings through first-principle calculations based on the density functional theory using ab initio plane wave pseudo-potential method within generalized-gradient approximations. Nine Tl atoms are found to form a QD occupying the attractive basin around the Si restatoms in the faulted half unit cell and the surface is semiconductor with an energy gap of 0.11 eV. The calculated band structure of Ti QD’s shows the bonding origin of surface states, confirming our experimental results. The origin of the difference in binding energy shift of each electron state is the interaction between electrons only in QD’s, leaving the electron states relative to QD’s unshifted. [1] L. Vitali, M. G. Ramsey, and F. P. Netzer, Phys. Rev. Lett. 83, 316 (1999).

K1.00010 Discerning thermal properties of entanglement in qubit rings using n-concurrence, YUVAL SANDERS, HILARY CARTERET, BARRY SANDERS, University of Calgary — We show that n-concurrence is an excellent tool for discerning the entanglement properties of qubit networks (e.g. rings) and demonstrate multiple entanglement revivals as temperature increases.

K1.00011 Floquet formulation for the investigation of multiphoton quantum interference in a superconducting qubit driven by a strong field, SANG-KIL SON, SHIH-I CHU, University of Kansas — We present a Floquet investigation of multiphoton quantum interference in a strongly driven superconducting qubit. The procedure involves a transformation of a time-dependent problem into an equivalent time-independent infinite-dimensional Floquet matrix eigenvalue problem. The results of a two-level qubit system show quantum interference fringes around multiphoton resonance positions in agreement with the experimental results of Oliver et al., Science 310, 1653 (2005). We further explore the interference patterns in terms of quasenergies and the resonance position shifts as the tunneling strength increased. The Floquet formulation promises a new and accurate approach for the investigation of quantum interference phenomenon in the qubits.

K1.00012 Analytical methods for design of surface-electrode ion traps, J.H. WESENBERG, J.M. AMINI, R.B. BLAKESTAD, J. BRITTON, K.R. BROWN, R.J. EPSTEIN, J.P. HOME, W.M. ITANO, J.D. JOST, C. LANGER1, D. LEIBFRIED, R. OZERI2, S. SEIDELIN, D.J. WINELAND, Time and Frequency Division, NIST, Boulder, Colorado 80305, USA — Surface-electrode ion trap are promising candidates for the large scale multi-zone ion traps which are required for large scale quantum information processing. Electrode design for surface-electrode traps is complicated by the low symmetry and the large exposed electrode area. We apply a simple method to obtain analytical expressions for the field of arbitrarily shaped surface-electrodes. The efficiency of this method compared to traditional boundary (BEM) or finite (FEM) element methods has allowed us to use numerical optimization techniques to help in the design of advanced trap structures, such as intersections and ion separation zones. Work supported by DTO and NIST. J.H.W. acknowledges support from the Danish Research Agency.

K1.00013 Quantum Simulation Circuits for Sparse Hamiltonians, NATHAN WIEBE, BARRY SANDERS, The University of Calgary — In 1982, Feynman suggested a quantum computer would efficiently simulate quantum systems and illustrated this concept with Heisenberg chains (Int. J. Theor. Phys. 21, 467), which are difficult to solve on a classical computer. Recently, building upon the work of Aharonov and Ta-Shma (Proc. 35th Annual ACM Symp. on Theory of Computing, 20-29), Berry, Ahokas, Cleve, and Sanders (arxiv:quant-ph/0508139) developed an algorithm that simulates state evolution for generic sparse time-independent Hamiltonians, which accounts for all resources and has a cost that is nearly linear in time. We present a quantum circuit protocol to implement this algorithm. Furthermore we discuss the adaptation of this scheme for a broad class of time-dependent Hamiltonians.

K1.00014 Quantum Simulators, Spin Systems, and Trapped Ions, WARREN LYBARGER, Los Alamos National Laboratory / UCLA, JOHN CHIAVERINI, ROLANDO SOMMA, DAVID LIZON, W. ROBERT SCARLETT, MALCOLM BOSHIER, DANA BERKELAND, Los Alamos National Laboratory — Many-quantum-spin systems cannot be efficiently simulated on classical computers as they require exponentially large resources. Yet many systems can be simulated efficiently with quantum simulators (QS) that do not require universal control like quantum computers. Following the work of Porras and Cirac [Phys. Rev. Lett. 92, 207901-1 (2004)] we discuss current experimental efforts at Los Alamos to implement a QS for Ising-like and Heisenberg-like models with trapped ion qubit “spins”. The states of the QS follow nearly the same equations of motion as the systems of interest, and unlike with real materials, the experimenter has the advantage of direct access to and control over the spins. We will discuss progress towards proof-of-principle investigations of two-ion simulations in a single-well trap, in which we use state-selective optical forces to induce ion-ion interactions.
K1.00015 Ion heating rates in scalable trap architectures for quantum computation1, R.J. EPSTEIN, D. LEIBFRIED, J.J. BOLLINGER, S. SEIDELIN, J.H. WESENBERG, N. SHIGA, J.M. AMINI, R.B. BLAKESTAD, J. BRITTON, K.R. BROWN, J.P. HOME, W.M. ITANO, J.D. JOST, E. KNILL, C. LANGER2, R. OZERI1, D.J. WINELAND, Time and Frequency Division, NIST, Boulder, CO 80305, USA — We describe the characterization of several microfabricated ion trap architectures for quantum computation. Our apparatus for testing planar ion trap chips features: a standardized chip carrier for ease of interchanging traps, a single-laser Raman sideband-cooling scheme, and photo-ionization loading of Mg+ ions. We measure the heating rate of an ion’s motional degree-of-freedom, a factor which limits multi-ionic logic gate fidelities. Two measurement techniques are compared, the standard Raman sideband technique and time-resolved fluorescence detection during Doppler re-cooling2. One of the traps, fabricated from gold on fused silica, shows heating rates below 1 quanta/ms (motional frequency = 5.3 MHz), boiling well for planar ion trap designs.

1Work supported by DTO and NIST.
2Present address: Lockheed Martin, Palmdale, CA
3Present address: Weizmann Institute of Science, Rehovot, Israel

K1.00016 A Computational Comparison of Ion Heating Rates in Conventional and Rotating rf-Electric Quadrupole Ion Traps1, MICHAEL CUMMINGS, PHILLIP ASHBY2, ROBERT THOMPSON — Two distinct field geometries are of interest for the containment of ions in linear rf-electric quadrupole ion traps: the conventional (or flapping) and the rotating forms of the trapping fields [1]. Although much theoretical and experimental work has been devoted to the multi-ion dynamics in conventional ion traps, only the single particle motion in the rotating geometry has been explored in any detail. Here, we present a computational study of the many particle dynamics for both trap geometries, focusing on the temperature dependent heating rates. A wide range of particle numbers and stability parameters (q values) are sampled, allowing for a detailed comparison of the thermal character of both traps. Additionally, the computational data are compared with the instability heating theory [2] and theoretical rf-heating rate calculations.


1This research has been supported by NSERC (Canada).
2Currently at McMaster University, Dept. of Physics and Astronomy

K1.00017 Multilayer Interconnects for Microfabricated Surface Electrode Ion Traps, JASON AMINI, SIGNE SEIDELIN, JANUS WESENBERG, JOE BRITTON, BRAD BLAKESTAD, KENTON BROWN, RYAN EPSTEIN, JONATHAN HOME, JOHN JOST, CHRIS LANGER1, DIETRICH LEIBFRIED, ROEE OZERI1, DAVID WINELAND, NIST — Microfabricated surface electrode traps for ions are a promising technology for building scalable trapping geometries for quantum information processing. We have expanded upon our single layer gold-on-fused-silica surface electrode trap [1] to include a second patterned conducting layer under the trapping electrodes and have demonstrated the fabrication of this architecture using standard microfabrication techniques. The multilayer approach allows for a significant increase in multi-zone trapping complexity and permits improved trapping structures that are otherwise unattainable in single layer designs without vertical interconnects through the wafer. Using improved calculational methods [2], we are in the process of optimizing the planar designs to create modular elements that can be joined to larger multi-zone trapping structures. Work supported by DTO and NIST.


K1.00018 Quantum projection noise and squeezing with ions in a Penning-Malmberg trap, N. SHIGA1, W.M. ITANO, J.J. BOLLINGER, NIST, Boulder, CO 80305 — We summarize initial progress towards making spin squeezed states with ~1000Be+ ions in a Penning-Malmberg trap. We use the ground-state electron spin-flip transition, which in the 4.5 T trap magnetic field has a 124 GHz transition frequency, as the ion qubit. With a 30 mW Gunn diode oscillator we have observed π-times as short as 100 μs. We have realized projection noise limited spectroscopy on this transition, which is a prerequisite for demonstrating spin squeezing. For entangling the ions we plan to use a generalization of the few ion qubit phase gate developed at NIST to generate an exp (iχJz^2) interaction between all of the ion qubits. This interaction can be implemented on a single plane of ions, with a motional sideband, stimulated Raman transition. We have observed fast (~1 ms) magnetic field fluctuations of our magnet through spin-echo spectroscopy. These fluctuations limit the amount of time that can be used to apply the squeezing.

1Supported by a DOD MURI program administered by ONR

K1.00019 Motional Narrowing of Optically Detected Single Nuclear Spin Qubit, LIANG JIANG, M.V. GURUDEV DUTT, LILY CHILDERESS, EMRE TOGAN, MIKHAIL LUKIN, Department of Physics, Harvard University — We study quantum dynamics of individual nuclear spin qubit coupled to optically excited, proximal single electron spin. We show that nuclear spin dephasing can be very slow, even under conditions of fast optical excitation. We present a detailed theoretical model for this process, which is related to motional narrowing in NMR as well as quantum Zeno effect. These results are compared with detailed experimental study of single nuclear spins associated with nitrogen-vacancy centers in diamond. Finally, we discuss the relevance of these results to realization of quantum information processing.

K1.00020 Quantum register based on individual electronic and nuclear spin qubits in diamond, EMRE TOGAN, M. V. GURUDEV DUTT, LILY CHILDERESS, LIANG JIANG, JERONIMO MAZE, Department of Physics, Harvard University, FEDOR JELEZKO, Physikalisches Institut, Universität Stuttgart, PHILIP HEMMER, Department of Electrical and Computer Engineering, Texas A & M University, MIKHAIL LUKIN, Department of Physics, Harvard University — We describe a technique that makes use of coherent manipulation of an individual electron spin and individual nuclear spins in its environment to create a controllable quantum register composed of a few quantum bits (qubits). Using optical and microwave radiation to control an electron spin associated with the Nitrogen-Vacancy (NV) color center in diamond, we demonstrate robust initialization of a two-qubit register at room temperature and transfer of arbitrary quantum states between electron and nuclear spin qubits. We further show that nuclear spin qubits can be well isolated from the electron spin, even during optical polarization and measurement of the electronic state. Finally, we observe coherent interactions between individual nuclear spin qubits, and demonstrate that they have excellent coherence properties. These registers can be used as a basis for scalable, optically coupled quantum information systems.
these results arise because the electron spin alters the properties of the nuclear spin bath, affecting both the coupling between nuclear spins.

K1.00022 Noise-induced Decoherence of Stark Wavepackets Studied Using an Echo Technique1, WEI ZHAO, JEFFREY MESTAYER, JIM LANCASTER, F. BARRY DUNNING, Department of Physics and Astronomy, Rice University, SHUHEI YOSHIDA, Vienna University of Technology, CARLOS REINHOLD, Oak Ridge National Laboratory, JOACHIM BURGDORFER, Vienna University of Technology — The decoherence of high-n Stark wavepackets induced by noise is examined using a quantum beat echo technique. Noise, i.e., coupling to the environment, causes irreversible dephasing of the wavepacket and reduces the amplitude of the echoes. Here we apply synthesized noise to Stark wavepackets and quantify their robustness against decoherence by measuring the size of the echoes. The wavepackets are produced by sudden application of a transverse dc field to quasi-one-dimensional n=350 Rydberg atoms. Their subsequent evolution is monitored using a half-cycle probe pulse. The technique can be applied on timescales much shorter than those associated with revivals allowing measurement of decoherence times even in the presence of very strong dephasing.

1Research supported by the DOE, the NSF, the WFW (Austria), and the Robert A. Welch Foundation.

K1.00023 Cascaded emission from cold atomic ensembles1, HSIANG-HUA JEN, Georgia Institute of Technology, STEWART JENKINS, Univ. of Insubria, ALEX KUZMICH, BRIAN KENNEDY, Georgia Institute of Technology — We study the phase matched two-photon cascade emission from a collection of cold alkali atoms induced by two color laser excitation. The cascade configuration, which has recently been employed for the generation of polarization-entangled photon pairs at infra-red and telecommunication wavelengths Chaneire et al. [PRL 96, 093604 (2006) ], exhibits superradiant time scales for the infra-red field component. We will present a theoretical analysis which explain the characteristic features observed.

1 NASA and NSF

K1.00024 Control of single neutral atoms for quantum information, MICHAEL GIBBONS, SOO KIM, KEVIN FORTIER, PEYMAN AHMADI, MICHAEL CHAPMAN, Georgia Institute of Technology — Experimentally, optical traps have suffered for many years from unexplained heating rates. These have limited the trap lifetime to an order of magnitude less than expected for the vacuum ranges attainable. Recently, we have achieved very long lifetimes of single rubidium atoms trapped in a 1-D optical lattice by optical molasses cooling. We have transported the laser cooled atoms, trapped in an optical lattice, to a high finesse cavity. Such long lived neutral atoms are of particular interest for quantum information storage and processing schemes.

K1.00025 Entangling Neutral Atoms with Symmetrization-Dependent Dynamics, NATHAN BACCOCK, RENE STOCK, Institute for Quantum Information Science, University of Calgary, MARK RAIZEN, Center for Nonlinear Dynamics and Department of Physics, University of Texas, Austin, BARRY SANDERS, Institute for Quantum Information Science, University of Calgary — Trapped neutral atoms provide a promising medium in which to perform quantum computations since they have long decoherence times and can easily be interfaced with light for single-qubit operations and measurements. Despite these advantages, reliable methods for entangling and transporting atomic qubits must be devised before practical atomic quantum information processing devices can be realized. We propose a method for entangling a pair of indistinguishable neutral atoms stored in separated optical dipole traps. We model this trapping potential in one dimension as a pair of Gaussian wells that can be brought together for atoms to interact. The dynamics of this process depend on the symmetrization parameters of the initial state, and by choosing the correct interaction time a controlled-phase gate can be designed. Adiabatic separation guarantees that the atoms end up in opposite traps. We provide both adiabatic and time-dependent numerical simulations of the entangling process. Additionally, we consider a novel method for creating entangled qubits via selective excitation of atoms in such optical dipole traps.

K1.00026 REACTIVE AND HEAVY-PARTICLE COLLISIONS –

K1.00027 L Sub-Shell Cross Sections measured for 75-300 keV protons on Selected Rare-Earth Elements. SAM J. CIPOLLA, Creighton University — L sub-shell x-ray production cross sections were measured for 75-300 keV proton impact on thick elemental targets ranging from Gd through Yb. X-ray yields were measured using a high-resolution Si(Li) detector with an ultra-thin window. The results were compared with ECPPSSR theory with and without the united-atom approximation for the binding-energy effect and the relativistic correction. Multiple ionization effects are also taken into account.

K1.00028 Signature of Target Excitation In Nitrogen Fragmentation, C.P. SAFVAN, JYOTI RAJPUT, SANKAR DE, A. ROY, Inter-University Accelerator Centre, New Delhi - 110067, India — Target excitation following ion-impact has been observed to play a significant role in multi-electron capture studies in ion-atom collision experiments. Probably this is the first report on the role of target excitation in ion-induced fragmentation of nitrogen [1]. The multiple ionization and fragmentation of N2 by ion impact is studied using position sensitive TOF technique in multi-hit coincidence mode in the LEIBF laboratory of IUAC, India. With Ar+ projectiles at a velocity of 1 a. u., we observe a total of seven fragmentation channels originating from multiply charged transient molecular ions. The kinetic energy release (KER) spectra of all the observed fragmentation pathways were extracted from the analyzed data on an event by event basis. Ab initio calculations were done for determining the potential energy curves for multiply charged nitrogen molecular ions to account for the observed KER using the quantum chemistry package GAMESS. The preference of symmetric charge breakup channels over the asymmetric ones is clearly observed. A signature of core excitation of the target molecule followed by Auger emission is observed in the kinetic energy spectra of the N+3-N+3+ fragmentation channel in the form of a clear distinct peak at 72 eV [1], this value being very close to the most probable KER in the case of N+3-N+3+fragmentation channel. Ref: [1] Jyoti Rajput et. al., PRA, 74, 032701 (2006)

K1.00029 Electron-impact excitation of dihydrogen sulfide in the VUV spectral region, ERIC VYSKOCIL, STEPHEN BROPETON, WŁADYSŁAW KEDZIERSKI, WILLIAM MCCONKEY — The electron-impact excitation of dihydrogen sulfide and charged fragments including atomic sulfur is presented in the VUV spectral range from 90 nm – 150 nm. Hydrogen sulfide gas was dissociated by a microwave discharge tube prior to injection into an interaction region where electron-impact excitation occurred. By comparing the discharge ‘on’ and discharge ‘off’ spectra, contributions to the spectra from dissociative excitation of the parent molecule and from direct excitation of the charged fragments could be determined. Excitation functions for the different spectral features were determined for electron energies from threshold to 200 eV.
K1.00030 Vibrationally-resolved Charge Transfer for Proton Collisions with CO$^+$, CHIH-YUAN LIN, PHILLIP STANCIL, University of Georgia, Y. LI, J.P. GU, H.P. LIEBERMANN, ROBERT BUENKER, University of Wuppertal, MINEO KIMURA, Kyushu University. — Electron capture by protons following collisions with carbon monoxide, and the reverse process, is studied with a quantum molecular-orbital coupled-channel method utilizing the infinite order sudden approximation for collision energies between 0.5 and 1000 eV/u. The potential surfaces and couplings, computed with the multireference single- and double-excitation (MRD-CI) method for a range of H$^+\cdot$CO orientation angles and C-O separations, are adopted in the scattering calculations. Results including vibrationally-resolved and orientation-angle- dependent cross sections are presented for a range of CO and CO$^+$ vibrational levels. Comparison with experiment is made where possible and the relevance of the reaction in astrophysics and atmospheric physics is discussed.

1NASA Grant No. NNC05GD98G and NSF grant INT-0300708.

K1.00031 Geometric and Isotopic Influences on the Fragmentation Patterns of Rapidly Ionized Methane and Ammonia$^1$, LAURA DOSHIER,AMY LUEKING, IVAN LEE, ERIC WELLS, Department of Physics, Augustaana College, SiouxFalls, SD 57197, ELI PARKE, MAT LEONARD, KEVIN D. CARNES, ITZIK BEN-ITZHAK, J.R. Macdonald Laboratory, Department of Physics, Kansas State University, Manhattan, KS 66506. — The fragmentation branching ratios of (deuterated) ammonia and methane ionized by 19 MeV F$^+$ and 4 MeV H$^+$ projectiles have been measured with an emphasis on dissociation channels that require bond rearrangement. For these projectiles, the collision time is approximately 10 attoseconds, a duration over which nuclear motion is negligible. As a result, the rearrangement occurs during the post-collision dissociation process and nuclear mass plays a role. Production of H$_2^+$ and H$_3^+$ ions, in coincidence with either neutral or ion fragments, was analyzed for these eight collision systems. Statistically significant isotopic effects are observed in some (e.g. H$^+$ + NH$_3^+$ → H$^+$ + N + H$_3^+$), but not all (e.g. F$^7+ +$ NH$_3^+$ → F$^{7+} +$ N + H$_3^+$), dissociation pathways.

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

K1.00032 Soft X-ray Line Emission Spectra from Highly-Charged Solar Wind Ions on Cometary Gases: N$^{5,6+}$ on CO$^+$, WINTHROP SMITH, KENNETH MILLER, Univ. of Connecticut, CHRISTOPHER VERZANI, Univ. Wisconsin - Stephens Pt., WESLEY GOHN, QUINTEN KESSEL, Univ. of Connecticut, STEVEN J. SMITH, ARA CHUTJIAN, NASA Jet Propulsion Lab/Caltech. — Laboratory measurements to benchmark space observations of x rays from comets approaching the sun were made using the highly-charged ion-beam facility at JPL and the UConn 1 m grazing-incidence CCD spectrometer. Beam-gas spectra are obtained from ions found in the solar wind on CO and other cometary gases: N$^{5,6+}$. This work has been supported by the U.S. Department of Energy.

K1.00033 Collision induced dissociation and dissociative capture of slow (keV) H$_2^+$ and HD$^+$ on atomic targets$^1$, NORA G. JOHNSON, A. MAX SAYLER, LEAH VAN NAHMEN, SAM FAHRENHOLTZ, ELI PARKE, D. HATHIRAMANI, J.W. MASEBERG, K.D. CARNES, I. BEN-ITZHAK, J.R. Macdonald Laboratory, Department of Physics, Kansas State University. — Collision induced dissociation (CID, e.g. H$_2^+$ + Ar(He) → H$^+$ + H + Ar(He)) and dissociative capture (DC, e.g. H$_2^+$ + Ar(He) → H$^+$ + H + Ar(He)→He$^+$) are measured and separated by 3D momentum imaging of the fragments. CID is further separated into two mechanisms: electronic (eCID) and vibrational (vCID) excitation, distinguished by the kinetic energy release and the momentum transfer to the center of mass of the projectile. Similarly, DC is separated into capture directly to the repulsive b$^3\Sigma^+_u$ state and predissociating c$^1\Pi_u$ state. Angular studies for both channels show vCID strongly prefers to be aligned perpendicularly to the beam direction whereas DC prefers parallel alignment. Our eCID data agrees nicely with theory [1].

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

K1.00034 Study of gas-phase chemistry in a hot-wire chemical vapor deposition reactor with trimethylsilane and hexamethyldisilane$^1$, BRETT EUSTERGERLING, XINMAO LI, YUJUN SHI, University of Calgary. — Gas-phase chemistry involved in the decomposition of trimethylsilane and hexamethyldisilane (HMDS) on a hot tungsten filament and the secondary gas-phase reactions in the HWCVD reactor has been studied using vacuum ultraviolet laser single photon ionization in tandem with TOF-MS. On the hot W filament, trimethylsilane is cracked to primary radicals and those later formed are found to be the main gas-phase reaction pathways in the reactor for both precursors. Characteristic reactions of trimethylsilane are those with (CH$_3$)$_3$Si and (CH$_3$)$_3$HSiCH$_2$ radicals directly or indirectly involved, resulting in the formation of peaks at m/z = 88, 118, 132, 146, 116 and 130. With relatively heavier radicals generated from the decomposition of HMDS, the characteristic reactions for HMDS are believed to be those producing peaks in higher mass region, such as peaks at m/z = 204, 218, 262, 276, and 290.

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

K1.00035 Spectral Hole Burning in the Dielectronic Recombination from a Continuum of Finite Bandwidth$^1$, EDWARD SHUMAN, WEI YANG, TOM GALLAGHER, University of Virginia. — The presence of an electric field converts the intermediate autoionizing Rydberg nℓ states, through which dielectronic recombination passes, into nk Stark states, which have autoionization and capture rates in excess of the radiative decay rates and contribute to dielectronic recombination. In zero field the high ℓ states do not contribute to dielectronic recombination, but the conversion to Stark states makes it possible and raises the dielectronic recombination rate. However, an electric field can also result in coupling to loss channels which locally reduce the dielectronic recombination rate. We have observed holes in the spectrum of dielectronic recombination from the Ba 6p$_3/2$8g continuum of finite bandwidth via the intermediate 6p$_3/2$4g states. The holes appear when an electric field is applied, and we attribute them to interaction with rapidly decaying 6p$_3/2$8ℓ states, which diverts flux from dielectronic recombination.

1This work has been supported by the U.S. Department of Energy.

K1.00037 Sinusoidal Regge Oscillations from Short Lived Resonances1, D. SOKOLOVSKI, The Queen’s University of Belfast, UK, Z. FELFLI, A.Z. MSEEZANE, Clark Atlanta University, SOKOLOVSKI COLLABORATION, FELFLI/MSEEZANE TEAM — It is well known that a resonance with a large angular life can produce sharp Breit-Wigner peaks in the energy dependence of integral cross sections [1,2]. Here we show that a short-lived resonance whose angular life is of order one of full rotation may produce a different kind of contribution to the integral cross section. This contribution has a sinuousoidal form and its frequency is determined by the rotational constant of the complex. As one of the examples, we analyze the Regge oscillations observed in numerical simulations of the $F + H_2 (v = 0, j = 0,\Omega = 0) \rightarrow FH'(v' = 2, j' = 0,\Omega' = 0) + H$ reaction. In particular, we show that these oscillations are produced by two overlapping resonances located near the transition state and the van der Waals well, respectively [3].

1 This work is supported part by NASA, the German Federal Ministry for Education and Research, and the German Research Council.

K1.00038 Dielectronic recombination in highly charged ions to explore correlated high-field few-electron dynamics and QED effects, Z. HARMAN, V. MAECKEL, A.J. GONZALEZ MARTINEZ, J.R. CRESPO LOPEZ-Urrutia, U.D. JENTSCHURA, C.H. KEITEL, H. TAWARA, J. ULLRICH, Max Planck Institute for Nuclear Physics, Heidelberg, Germany, A.N. ARTEMYEV, I.I. TUPITSYN, St. Petersburg State University, Russia — The study of dielectronic recombination with highly charged few-electron ions provides unique possibilities for investigating correlation and QED effects in many-electron systems as well as for exploring the relativistic dynamics of recombination processes. We calculated resonance energies and cross sections for KLL recombination channels into highly-charged Fe, Kr, Xe, Ba, W, and Hg ions [1], applying the possibilities for investigating correlation and QED effects in many-electron systems as well as for exploring the relativistic dynamics of recombination processes. We calculated resonance energies and cross sections for KLL recombination channels into highly-charged Fe, Kr, Xe, Ba, W, and Hg ions [1], applying the possibilities for investigating correlation and QED effects in many-electron systems as well as for exploring the relativistic dynamics of recombination processes. We calculated resonance energies and cross sections for KLL recombination channels into highly-charged Fe, Kr, Xe, Ba, W, and Hg ions [1], applying the possibilities for investigating correlation and QED effects in many-electron systems as well as for exploring the relativistic dynamics of recombination processes. We calculated resonance energies and cross sections for KLL recombination channels into highly-charged Fe, Kr, Xe, Ba, W, and Hg ions [1], applying the possibilities for investigating correlation and QED effects in many-electron systems as well as for exploring the relativistic dynamics of recombination processes. We calculated resonance energies and cross sections for KLL recombination channels into highly-charged Fe, Kr, Xe, Ba, W, and Hg ions [1], applying the possibilities for investigating correlation and QED effects in many-electron systems as well as for exploring the relativistic dynamics of recombination processes. We calculated resonance energies and cross sections for KLL recombination channels into highly-charged Fe, Kr, Xe, Ba, W, and Hg ions [1], applying the possibilities for investigating correlation and QED effects in many-electron systems as well as for exploring the relativistic dynamics of recombination processes. We calculated resonance energies and cross sections for KLL recombination channels into highly-charged Fe, Kr, Xe, Ba, W, and Hg ions [1], applying the possibilities for investigating correlation and QED effects in many-electron systems as well as for exploring the relativistic dynamics of recombination processes. We calculated resonance energies and cross sections for KLL recombination channels into highly-charged Fe, Kr, Xe, Ba, W, and Hg ions [1], applying the possibilities for investigating correlation and QED effects in many-electron systems as well as for exploring the relativistic dynamics of recombination processes. We calculated resonance energies and cross sections for KLL recombination channels into highly-charged Fe, Kr, Xe, Ba, W, and Hg ions [1], applying the possibilities for investigating correlation and QED effects in many-electron systems as well as for exploring the relativistic dynamics of recombination processes.

1 This work is supported part by NASA, the German Federal Ministry for Education and Research, and the German Research Council.

K1.00039 Numerical calculation of supercritical Dirac resonance parameters by analytic continuation1, EDWARD ACKAD, MARKO HORBATSCH, York University, Toronto, Ontario, Canada — The spectrum of the Dirac equation for hydrogen-like systems with extended nuclei becomes complicated when the nuclear charge exceeds a critical value $Z \approx 170$, since the lowest bound state becomes a resonance in the negative energy continuum. We address the problem of computing the resonance parameters by extending the mapped Fourier grid method to incorporate either complex scaling (CS) of the radial coordinate, or alternatively a complex absorbing potential (CAP). The method is tested on the case of quasimolecular Uranium-Californium collisions in the monopole approximation. The method of CAP is found to be more stable than CS [1]. The method to incorporate either complex scaling (CS) of the radial coordinate, or alternatively a complex absorbing potential (CAP). The method is tested on the case of quasimolecular Uranium-Californium collisions in the monopole approximation. The method of CAP is found to be more stable than CS [1].

1 This work is supported part by NASA, the German Federal Ministry for Education and Research, and the German Research Council.

K1.00040 Differential cross section ratios for $p + \text{He}$ collisions1, MICHAEL SCHULZ, University of Missouri-Rolla, AHMAD HASAN, UAE University, TIBOR VAJNI, Keckskemet College, MIROSŁAW ZAPUKHLYAK, TOM KIRCHNER, TU Clausthal — We have measured differential cross sections for single capture, double capture, and transfer excitation in $p + \text{He}$ collisions. In the double to single capture cross section ratios $R_{DC}$ we observe peak structures around 0.5 to 1.0 mrad similar to those reported previously for the double to single ionization and transfer-ionization to single capture ratios $R_{DI}$ and $R_{TI}$, respectively. However, surprisingly in our data for $R_{DC}$ the relative importance of these peaks maximize at a relatively small projectile energy of about 50 to 75 keV while in $R_{DI}$ and $R_{TI}$ the structures become increasingly pronounced with increasing projectile energy and are not observed below approximately 200 keV. We also found a pronounced peak structure in the double ratio $R = R_{TE}/R_{DE}$, where $R_{TE}$ is the transfer excitation to single capture ratio and $R_{DE}$ the double to single excitation ratio1. Our theoretical calculation qualitatively reproduces the peak structure in $R$ if the elastic scattering between the projectile and the residual target ion is treated quantum-mechanically. Finally, we revisited doubly differential single ionization data reported earlier2 and found peak structures in the ratios between cross sections for different electron energies. 1W. Htwe et al., PRL 73, 1348 (1994) 2T. Vajnai et al., PRL 74, 3588 (1995)

1Supported by NSF.
K1.00041 Electron Transfer, Excitation, and Ionization in Collisions between α Particles and H(1s) Atoms, THOMAS WINTER, Pennsylvania State University — Cross sections have been determined for electron transfer and excitation to each individual state up to 3d, to all states, and for ionization in 3-2400 keV α-H collisions using a double-center, 80-251-state Sturmian basis, substantially expanding the Sturmian calculations carried out a quarter of a century ago, which were limited to 19-24 states and reported only electron transfer to all states, and only for a much more limited energy range. At the lower and intermediate energies, cross sections have now been obtained with a basis of approximately the same number of Sturmians on each nuclear center, while at α energies of at least 800 keV results they have also been obtained with a predominantly target-centered basis. The results for capture are better converged at the lower energies, while those for excitation and ionization, at the higher energies, where they may also be compared to Born results. Except at low energies, results may be compared with the atomic- plus-pseudostate results of Kuang and Lin, while at all energies, the results for total capture and ionization may be compared with the coupled-Gaussian results of Toshima.


K1.00042 Time ordering in atomic collisions, J.H. MCGUIRE, Tulane, A.L. GODUNOV, ODU, KH KH SHAKOV, L. KAPLAN, A. BURIN, D. USKOV, Tulane — Time ordering constrains interactions to occur in increasing (or decreasing) order. This places a constraint on the time evolution of the system and can lead to correlations in time of different particles in a few/many body system. Unlike overall time reversal, time ordering is not a conserved symmetry of the atomic system. A number of examples of observable effects of time ordering are presented. A convenient way to describe time ordering is to define the limit of no time ordering by replacing the instantaneous interaction by its time average. This is similar to the way in which spatial ordering is defined. Like spatial correlation, time ordering is usually formulated in the interaction representation. The effects of time ordering can differ in different representations. In energy space, conjugate to time space, time ordering is imposed as the iϵ term in the Greens’ function that corresponds to an initial condition (usually incoming plane waves and outgoing scattered waves). This permits off-energy-shell (energy non-conserving) fluctuations during the collision consistent with the Uncertainty Principle.

K1.00043 Development and Construction of a Novel Apparatus for Studying Anion-Neutral Reactions,1 B. SEREDYUK, H. BRUNHS, H. KRECKEL, W. MITTTHUMSIRI, D.W. SAVIN, Columbia Astrophysics Laboratory, M.E. BANNISTER, C.C. HAVENER, Oak Ridge National Laboratory, A. DORN, Max-Planck-Institute for Nuclear Physics, O. HEBER, M.L. RAPPAPORT, Weizmann Institute of Science, A.M. COVINGTON, University of Nevada at Reno — We are developing a novel apparatus at the Columbia Astrophysics Laboratory to study anion-neutral reactions. We will use fast, merged anion-neutral beams and detect the charged end products. Laboratory beam energies will be in the keV range. Because the beams run co-linear, center-of-mass energies from the sub-eV to keV range can be achieved. Proof-of-principle measurements will be carried out using the associative detachment reaction \( \text{H}^+ + \text{H} → \text{H}_2^+ → \text{H}_2 + e^- \). Published values for this process differ by over a factor of 5. Our proposed research will help to resolve this fundamental issue. We will present our current progress on the design and construction of this apparatus. Future possible research directions include adding a cold molecular anion source in order to study reactions of the type such as \( X + YZ^- \). This will allow investigations into a wide range of anion-neutral reactions.

1This work is supported in part by the NSF Chemistry Research Instrumentation and Facilities: Instrument Development (CRIF:ID) Program.

K1.00044 Theoretical Calculations for Transfer-Excitation and Transfer-Ionization, A.L. HARRIS, J.L. PEACHER, M. SCHULZ, D.H. MADISON, University of Missouri-Rolla — Theoretical fully differential cross sections (FDCS) will be compared with experimental results for transfer-excitation and transfer-ionization occurring in proton-helium collisions. In the experiments, the incident proton captures one electron from a helium atom, and the remaining electron is left either in an excited bound state of the helium ion, or is ejected into the continuum as a free particle. The transfer-excitation experiments have been performed in Rolla, MO and the transfer-ionization experiments have been performed in Frankfurt, Germany. The theoretical approach we use is a full four-body approach, taking each particle into account. This results in a nine dimensional integral to evaluate the T-matrix. For transfer-excitation, the incident projectile and the outgoing hydrogen atom are treated as Hartree-Fock distorted waves, and a Hylleraas wavefunction is used for the initial state helium atom. In the final state, bound hydrogenic wavefunctions are used for the hydrogen atom and the residual ion. In the case of transfer-ionization, the ejected electron is treated as a Hartree-Fock distorted wave instead of a bound hydrogenic.

K1.00045 A Subnanosecond Ion Source for µm-focused Ion Beams, C. HÖHR, D. FISCHER, R. MOSHAMMER, A. DORN, J. ULLRICH, Max-Planck-Institut fuer Kernphysik, Heidelberg, Germany — A new, compact design of an ion source delivers ns-pulsed ion beams with low emittance, which can be focused to µm size. By using a high-power femtosecond (25 fs) laser pulse focused into a 10−6 mbar region, ions at very low temperatures are produced in the small focal volume (5 µm diameter by 20 µm length) through the simultaneous absorption of a high number of infrared photons. These ions are born in a cold environment and not in a hot plasma, and consequently have temperatures well below 10 K. The generated ion pulse (up to several thousand ions per bunch) is extracted from the source volume with ion optics that have been carefully tailored through simulations. Externally triggered, its subnanosecond duration and even smaller time jitter allows it to be superimposed with other pulses.

1present adress: TRIUMF, Vancouver, Canada


3Supported by the National Science Foundation, CREST Program

K1.00047 PHOTON INTERACTIONS WITH ATOMS, IONS AND MOLECULES; STRONG FIELD LASER PROCESSES —
K1.00048 The ground state and doubly excited $^{1,3}P^0$ states of the plasma-embedded Li$^+$ ion$^1$. SABYASACHI KAR, Y.K. HO, Institute of Atomic and Molecular Sciences, Academia Sinica, Taipei, Taiwan, ROC. — With the recent advancement for laser plasmas in laser fusion laboratories$[1]$ and with the recent experimental measurement on the doubly excited resonances in photo-ionization spectrum of Li$^+$ using the photon-ion merged-beam at the Advanced Light Source$[2]$, it is of interest to investigate the bound states and resonance states of Li$^+$ under the influence external environments produced by the charge-neutral background such as that of a plasma. The plasma effect is taken care of by using a screened Coulomb potential obtained from the Debye model. A correlated wave function has been used to represent the correlation effect between the charged particles. The ground state of Li$^+$ in plasmas for different screening parameters has been estimated in the framework of Rayleigh-Ritz variational principle. In addition, a total of 18 resonances (9 each for $^{1,3}P^0$ and $^{3}P^0$ states) below the $n=-2$ Li$^+$ thresholds has been estimated by calculating the density of states using the stabilization method. The resonance energies and widths for various Debye parameters ranging from infinity to a small value for these $^{1,3}P^0$ resonance states are reported.$[1]$ S. NaKai, K. Mima, Rep. Prog. Phys. 67, 321 (2004). $[2]$ S. W. J. Scully et al, J. Phys. B 39, 3957 (2006).

$^1$This work is supported by the National Science Council of Taiwan, ROC.

K1.00049 Photoelectron momentum spectra for multiphoton ionization of Hydrogen atoms by intense laser pulses$^1$. SERGE OVCHINNIKOV. University of Tennessee, JOSEPH MACEK, University of Tennessee / ORNL. — Full three-dimensional electron momentum distribution for multiphoton ionization of Hydrogen atoms by intense laser pulses are calculated by solving the time-dependent solutions of Schrödinger equation on a three-dimensional lattice in a scaled coordinate representation (CSLDSE). This approach allows one to circumvent many difficulties related to the propagation of wave function to macroscopic distances.

$^1$This work is supported by DOE Grant No. DE-FG02-02ER15283

K1.00050 Efficient Photoionization Loading of Ytterbium and Indium Ion Traps$^1$, LI-BANG WANG, TUAN NGUYEN, MARTIN SCHAUER, JUSTIN TORGERSON, Los Alamos National Laboratory. — We aim to perform precision optical spectroscopy on narrow transitions of In$^+$ and Yb$^{2+}$ to search for possible time variation of fine-structure constant $\alpha$. The high sensitivity of a transition frequency in Yb$^{2+}$ to $\alpha$ and its insensitivity to external fields make one of the best systems to test the time variation of fine-structure constant. In this report, we present a simple and efficient method to load a Paul trap with In$^+$ and Yb$^{+}$ ions. Resonant lasers from blue laser diodes at 410 nm and 399 nm are used to excite $5\Pi_1^1/2 - 6\Sigma_1^1/2$ transition of In and $6\Sigma_1^1 - 6\Pi_1^1$ transition of Yb, respectively. A second photon from the same 410 nm laser drives the In atoms into the continuum, while the Yb atoms are excited to high-lying Rydberg states by the same 399 nm laser and then subsequently ionized by the presence of a strong RF field. The progress of laser cooling of single trapped In$^+$ and Yb$^{+}$ ions, the proposed method of producing doubly-ionized Yb$^{2+}$ ions, and our approach using a frequency-comb laser for direct spectroscopy of clock transitions will be discussed. This work is supported by Los Alamos National Laboratory LDRD.

K1.00051 Multiphoton Ionization of Hydrogen Atoms in a Circularly Polarized Strong Radiation Field$^1$, A.S. TITI, G.W.F. DRAKE, University of Windsor. — The scattering matrix for the multiphoton ionization of a hydrogen atom in a circularly polarized strong radiation field, where the Coulomb potential is also included, is calculated. This leads to a divergent scattering matrix. By carrying out a unitary transformation to a frame in which the electron sees an oscillating nucleus, the singularity can be isolated and removed. The expression for the resulting nonsingular scattering matrix is written in terms of Bessel functions (representing direct single scattering) and Anger functions (representing rescattering). Both contributions interfere quantum mechanically. Intuitively, this provides a direct link to a path integral formulation of the problem. Finally, to compare our calculations with other calculations and to experimental results, the angular distribution of the ejected electrons is computed.

$^1$Research supported by NSERC

K1.00052 Anion and cation formation following Cl (1s) and S (1s) excitation in the SOCl$_2$ molecule$^1$, L.C. COUTINHO, G.G.B. DE SOUZA, Instituto de Química, Universidade Federal do Rio de Janeiro Brazil, A.S. SCHLACHTER, W.C. STOLTE, AMPHOL WONGJAMRAS$^2$, Lawrence Berkeley National Laboratory. — The ionization of deep core-level electrons is normally followed by a complicated array of processes involving cascading Auger mechanisms and giving rise to highly charged species. In contrast, the ionization of shallow core-level electrons in molecules is particularly interesting due to the low probability of formation; they usually originate from decay pathways distinct from the pathways associated with cation formation. In the present work, cationic and anionic mass spectrometry results are presented for the SOCl$_2$ molecule, excited both in the Cl (1s) and in the S (1s) edges in experiments at the ALS beamline 9.3.1.

$^1$The authors acknowledge CNPq and FAPERJ (Brazil) for financial assistance.

$^2$also at Chiang Mai University

K1.00053 Repulsive Rydberg States and Dissociative Ionization$^1$, LUTZ HUWEL, HONG CHEN, Wesleyan University. — We have performed experimental studies of the competition between direct and dissociative ionization of Na$_2$ in single ro-vibrational levels of the $2^1\Pi_0^+$ state. Excitation and ionization of the molecules is achieved in a molecular beam and with a two-color, three-photon optical-optical double resonance (OODR) technique. Total excitation energies range from about 700 to about 1400 cm$^{-1}$ above threshold for ground state dissociative ionization. Discrimination of fragment atomic Na$^+$ from molecular Na$_2^+$ ions is accomplished with a linear Time-of-Flight spectrometer. We observe Na$^+$:Na$_2^+$ ion ratios ranging from about 0.05 to a about 0.15. We have developed a semi-classical model that accounts reasonably well for the observed behavior of the ratio. The model is based on the assumption that dissociative ionization occurs in competition between autoionization and dissociation along repulsive neutral Rydberg states converging to the Na$^+_2$ $^{1}2\Sigma^+_u$ potential. Single adjustable model parameter is the autoionization lifetime. A chi-square procedure yields quite reasonable agreement with the experimental data suggesting autoionization lifetimes of the order of the corresponding Bohr orbit time. Details of the experiment and the model will be presented.

$^1$This work is supported by the National Science Foundation.
K1.00054 Electron-correlation induced blue-shift of oscillator strength in photoabsorption by clusters, HIMADRI CHAKRABORTY, Northwest Missouri State University, Maryville, MO 64468, MOHAMED MADJET, Freie Universitaet, 14195 Berlin, Germany, STEVE MANSOOL, Georgia State University, Atlanta, GA 30303. We performed investigations on the role of electron correlations in the photoabsorption of several sodium metal-clusters and fullerenes. We describe the electronic structure of the valence electron cloud by the Local Density Approximation (LDA) after representing the residual ions by a classical spherical jellium background. The response of the system to an external electromagnetic field is calculated by an independent particle (IP) LDA scheme that completely disregards electron-electron correlations. For all systems considered the IP result of photoabsorption cross section is characterized by predominant oscillator strength (OS) density below the first ionization threshold, the discrete part of the spectrum. We carried out separate calculations by appropriately including the electron correlation in a time dependent LDA frame. The resulting absorption cross sections generically indicate the transfer of OS density above the first ionization threshold as a direct consequence of the correlation. The blue-shifted OS density forms the plasmon resonances, the character of which, however, depends on the specifics of geometry and size of the system.

K1.00055 Emission of a Correlated Photo Electron Pair from Molecular Hydrogen: A T. Young Double Slit Experiment, THORSTEN WEBER ET AL., Lawrence Berkeley National Lab — We have studied experimentally the influence of the molecular alignment and spacing on the electron emission from a two body Coulomb potential induced by single photon absorption with 130, 160, 200 and 240 eV circular polarized light at the Advanced Light Source. Applying successfully the technique of COLTRIMS, it was possible to measure fully differential cross sections (FDCS) for the photo double photo ionization of hydrogen for fixed in space molecular orientations by detecting three particles in coincidence. The measurements covered 4π solid angle. We present angular distributions of the electrons studying the influence of diffraction, symmetry effects, selection rules and molecular orientations in body fixed frames. Thus for the first time a T. Young double slit experiment of a correlated electron pair inside a hydrogen molecule can be presented. We can illustrate the evolution from knock-off to shake-off processes and the interference of single particles as well as correlated pairs, while changing the deposited photon energy as well as the energy sharing of the two electrons. In addition the angular distributions show a distinct dependency on the Kinetic Energy Release (KER) of the recoiling ions, e.g. the size of the molecular double slt. The experimental results are also compared with quantum mechanical calculations.

K1.00056 Double Photoionization of Adamantane1, RALF WEHLITZ, Synchrotron Radiation Center, Univ. of Wisconsin - Madison, MAX YOUNG2, Univ. of Idaho - Moscow, PAVLE JURANIC, Synchrotron Radiation Center, Univ. of Wisconsin - Madison. We have measured double-to-single ionization cross-section ratios of adamantane (C30H30) in gas phase using photons of the Synchrotron Radiation Center (SRC). Adamantane, which is the first in the family of diamandoids, has a unique cage structure — the same structure that is found in the diamond crystal lattice. Thus, adamantane can be viewed as the smallest piece of diamond. Its cage structure prompted us to measure the first double-to-single photoionization ratios over a large photon energy range because previously we have found a surprising relation between modulations in that ratio and geometrical dimensions of a C60 cluster. In contrast to C60, adamantane does not have a “regular” structure and has additional hydrogen atoms attached to its cage. We will present our new data for adamantane and compare them to C60.

1The SRC is supported by NSF Grant No. DMR-0537588. 
2Supported by the NSF REU Program.

K1.00057 Modulations in the Double-to-Single Photoionization Cross Section Ratio of Benzene1, PAVLE JURANIC, RALF WEHLITZ, Synchrotron Radiation Center, University of Wisconsin-Madison, MAX YOUNG, University of Idaho-Moscow. In our previous experiments, we have observed the existence of modulations in the relative double-to-single photoionization cross section ratio of C60, the de Broglie wavelengths of the excess (above double ionization threshold) energies of these modulations closely matched inter-atomic distances within the C60 molecule. We have conducted further experiments with benzene, which has a much simpler structure than C60, to find out whether these modulations exist and can be similarly linked to inter-atomic distances in other molecules. The results of the experiment indicate that there seems to be such modulations in benzene.

1The SRC is supported by NSF grant No. DMR-0537588. Additional acknowledgment goes to the NSF REU program which supported M. Young’s research.

K1.00058 Extension of High Harmonic Generation Cutoff via Coherent Control of Intense Few-Cycle Chirped Laser Pulses1, JUAN J. CARRERA, SHIH-I. CHU, University of Kansas — We present an ab initio quantum investigation of the high-order harmonic generation (HHG) cutoff extension using intense few-cycle chirped laser pulses. For few-cycle chirped driving laser pulse, it is shown that significant cutoff extension can be achieved through the optimization of the chirping rate parameters. The HHG power spectrum is calculated by solving accurately and efficiently the time-dependent Schrödinger equation by means of the time-dependent generalized pseudospectral method. The time-frequency characteristics of the HHG power spectrum are analyzed in details by means of the wavelet transform of the time-dependent induced dipole acceleration. In addition, we perform classical trajectory simulation of the strong-field electron dynamics and electron return map. It is found that the quantum and classical results provide complementary and consistent information regarding the underlying mechanisms responsible for the substantial extension of the cutoff region.

1Department of Energy, and by NSF.

K1.00059 Self-interaction-free TDDFT for nonperturbative treatment of multiphoton processes of heteronuclear diatomic molecular systems in intense laser fields, JOHN HESLAR, SHIH-I. CHU, University of Kansas — We present a self-interaction-free time-dependent density-functional theory (TDDFT) with proper asymptotic long-range potential for nonperturbative treatment of multiphoton processes of many-electron heteronuclear molecular systems in intense laser fields. A time-dependent generalized pseudospectral method is developed with the use of a new mass-weighted prolate spheroidal coordinate system for accurate solution of the electronic structure and TDDFT equations for two-center heteronuclear diatomic systems. The procedure allows nonuniform and optimal spatial grid discretization of the Hamiltonian in the adapted prolate spheroidal coordinates and a split operator scheme in energy representation is used for the time propagation of individual molecular spin orbitals in space and time. The theory is applied to a detailed ab-initio study of high-order harmonic generation (HHG) and multiphoton ionization processes of CO in intense laser fields. Both even and odd-order harmonics are predicted for the CO molecule.
K1.00060 Relativistic Dynamics of highly charged hydrogen-like systems exposed to intense high-frequency electromagnetic fields, EVA LINDROTH, SØLVE SELSTØ, JAKOB BENGTSSON, Stockholm University — We solve the time dependent Dirac equation in a basis consisting of the eigenstates of the field free Hamiltonian $H_0 = c_0 \alpha \cdot p + V(r) + m c^2 \beta$. The dynamics induced by the time dependent perturbation, $H_\nu = c_\alpha \cdot A(r, t)$, in the velocity gauge, or equivalently $H_\nu = r \cdot E(r, t)(1 - c^2 \hat{k})$ in the length gauge, is resolved by solving the first order differential equation arising from the expansion. The number of continuum states needed in order to get converged results is reduced by complex scaling of the coordinates, $r \rightarrow r e^{i\kappa}$. We investigate the importance of relativistic effects for various field strengths, $E_0$, and nuclear charges by comparing the solutions of the Dirac equation with those of the Schrödinger equation. The dynamics is described both within and beyond the dipole approximation $(A(r, t) \approx A(t))$. For high $E_0$ and high photon energy, $\hbar \omega$, it is clear that this approximation breaks down. However, for increasing $Z$, the electron is increasingly tightly bound, which to some extent reduces the importance of non-dipole effects.

K1.00061 High-harmonic generation with relativistic laser intensities, CARL SCHROEDER, ERIC ESAREY, WIM LEEMANS, Lawrence Berkeley National Laboratory — A method for producing hard x-rays via high-harmonic generation using ultra-intense lasers is proposed. The method relies on caviation and ion channel formation by the ponderomotive force of a short, ultra-intense laser pulse or the space charge force of a dense, energetic electron beam. A second laser produces high harmonics in the electron-free cavity. A counter-propagating laser is used to eliminate the longitudinal motion owing to the magnetic component of the Lorentz force in the relativistic regime. A counter-propagating laser pulse train is proposed for quasi-phase matching. This method enables the reach of high-harmonic generation to be extended to the sub-Å regime.

1Supported by the U.S. DOE under Contract No. DE-AC02-65CH11231.

K1.00062 Many-mode Floquet theoretical approach for probing high harmonic generation in intense frequency-comb laser fields, SANG-KIL SON, SHIH-I CHU, University of Kansas — We extend the many-mode Floquet theorem (MMFT) [Chu and Tellevn, Phys. Rep. 390, 1 (2004)] for the investigation of high harmonic generation of a two-level system driven by intense frequency-comb laser fields. The frequency comb structure generated by a train of short laser pulses can be represented by a combination of the main frequency and the repetition frequency. The MMFT allows non-perturbative and accurate treatment of the interaction of a quantum system with the frequency comb laser fields. We observe that harmonic generation of the two-level system is dramatically enhanced by controlling the repetition frequency and the phase difference between pulses, due to simultaneous resonances.

1Supported by DOE

K1.00063 The Effect Of Focal Geometry On Radiation From Atomic Ionization In An Ultrastrong/ULtrafast Laser Field, ISAAC GHEBREGZIABHER, B.C. WALKER, Department of Physics and Astronomy, University of Delaware, Newark, DE 19716 — We use a tunneling-Monte-Carlo model to calculate the dynamics and emitted Larmor radiation from electrons ionized in an ultrashort/ultraintense pulsed laser focus over the intensity range from $10^{17}$ to $10^{20}$ W/cm². We find the spatial variation of a laser field can no longer be neglected at laser intensities leading to relativistic effects. Adopting a one-dimensional or plane wave approximation overestimates the total radiated energy by a factor as high as two orders of magnitude. Despite this, the spectral amplitude of the radiated high-energy photons from ionization in a laser focus is as high as that in the plane wave case since the laser focus imparts an extra boost of speed for electrons exiting the focus. Moreover, ionization in a laser focus limits the effective radiation volume to a few fraction of $\mu$m³ leading to more coherent radiation. For the ionization of Na¹⁰⁷ in a laser focus of intensity $1.22 \times 10^{20}$ W/cm², we find the peak radiation yield extending to photon energies of 580eV. In the plane wave case, we find radiation extending to photon energies of 560eV.

K1.00064 Semi-classical theory of diffraction imaging in strong laser fields, RYAN MURRAY, University of Waterloo, MISHA IVANOV, National Reseach Council — We present an analysis of how intense, few-cycle infrared laser pulses can be used to image the structure of small molecules with nearly 3 fs temporal and sub-Å spatial resolution. We perform numerical calculations using semi-classical techniques to obtain diffraction images of monatomic and diatomic nuclei. We then compare this to fully quantum calculations. We also discuss the strengths and weaknesses of our method, and why the semi-classical approach is more tractable than typical quantum calculations.

K1.00065 EIT AND QUANTUM MEMORY / COHERENT CONTROL —

K1.00066 Characterization of decoherence in electromagnetically induced transparency for applications in storage of light, EDEN FIGUEROA, JUERGEN APPEL, University of Calgary, FRANK VEWINGER, University of Bonn, ALEXANDER LVOVSKY, University of Calgary — Electromagnetically-induced transparency (EIT) has many applications in quantum information, particularly in quantum memory for light [1]. These applications require understanding of the phenomena responsible for decoherence in such processes. Insight into this question can be gained by being able to measure the width of the EIT resonance as a function of the pump field intensity. We report characterization of EIT resonances in the D1 line of Rb ⁸⁷ under various experimental conditions. The dependence of the EIT linewidth on the power of the control field was investigated, at various temperatures, for lambda level configurations associated with different hyperfine levels of the atomic ground state as well as magnetic sublevels of the same hyperfine level. Strictly linear behavior was observed in all cases. Our results were inconsistent with a widely accepted theory where population exchange between the ground levels is assumed to be the main decoherence mechanism [2]. We therefore formulated a new theory assuming pure dephasing (decay of off-diagonal matrix elements) as the new mechanism. Our data shows this theory to be in good agreement with our experiments. 1. D. F. Phillips, A. Fleischhauer, A. Mair, R. L. Walsworth, and M. D. Lukin, Phys. Rev. Lett. 86, 783 (2001). 2. H. Lee, Y. Rostovtsev, C. J. Bednar, and A. Javan, Appl. Phys. B 76, 33 (2003).

1NSERC,CFI,AIF,CIAR.

K1.00067 Progress Towards High Efficiency Atom-Photon Interface with Atomic Ensembles, ALEX NEIMIROVSKI, PHILIP WALTHER, ALEXEY GÖRŠKOV, ALEXANDER ZIBROV, MIKHAIL LUKIN, Harvard University — We describe our progress towards the generation and manipulation of narrow-bandwidth single photons and entangled photon pairs using a room-temperature ensemble of 87Rb atoms. Our method involves the creation of a collective atomic coherence via Raman scattering and projective measurement, followed by the coherent transfer of this atomic coherence to photons using electromagnetically induced transparency (EIT). We describe our current efforts towards developing a high performance system. These include optimization of the atomic level scheme, timing and preparation sequence, and buffer gas pressures.

2Supported by DARPA.
K1.00068 Many-particle effects in the propagation of slow light through atomic gases, IYAD MAHMOUD, KARL-PETER MÁRZLIN, BARRY SANDERS, University of Calgary — The optical properties of an atomic gas, including the dramatic reduction of the group velocity of light in electromagnetically induced transparency, usually grow with the density of atoms in the medium. However, in atomic gases of high density the resonant dipole-dipole interaction (DDI) will generate atom-atom correlations that can significantly alter the optical response of the medium. We present a theoretical analysis of the influence of DDI on the optical properties of a gas of three-level atoms in Δ configuration in which electromagnetically induced transparency is possible. Our novel method combines dressed states of quantum optics with the Keldysh diagram technique of non-equilibrium many-body theory and is particularly suited to describe atom-atom correlations in systems exhibiting coherent population trapping. We derive the susceptibility of the atomic gas from the properties of the many-body Green’s function and analyze its dependence on the temperature and density of the gas. The diagram technique also allows us to develop an intuitive picture of the physics of the propagation of light through a dense gas.

K1.00069 Modeling Loss-less Negative Refraction, TIMOTHY BRAGDON, SUSANNE YELIN, University of Connecticut — We use a model of a two-level system to simulate negative refractive index without absorptive losses due to gain enhancement. We compare this with our earlier ideas on negative refraction based on electromagnetically induced transparency (EIT). Then, we report the effects of phase noise on the resultant signal for import in signal fidelity issues.

K1.00070 Negative refraction without absorption: coherence effects, gain and local field corrections, JÜRGEN KASTEL, MICHAEL FLEISCHHAUER, TU Kaiserslautern, Kaiserslautern, Germany, GEDIMINAS JUZELIUNAS, ITPA of Vilnius University, Vilnius, Lithuania, SUSANNE F. YELIN, University of Connecticut, Storrs, CT, USA; ITAMP, Cambridge, MA, USA; RONALD L. WALSWORTH, Harvard University and ITAMP, Cambridge, MA, USA — Negative refraction of electromagnetic radiation is currently one of the most active areas of photonics research. Despite remarkable recent progress, a key challenge remains the realization of negative refraction without absorption. We discuss different ways to alleviate this problem: the coupling of an electric and a magnetic resonance together with quantum interference effects similar to EIT; compensation of absorption by introducing gain media. Furthermore surprisingly Clausius-Mossotti local field corrections for magneto-dielectric media in the high density limit result always in negative refraction with vanishing absorption.

K1.00071 Large fractional delay for slow and stored light in atomic vapor, IRINA NOVIKOVA, DAVID PHILLIPS, RONALD WALSWORTH, Harvard-Smithsonian — Large fractional delay is important in slow and stored light for many potential applications, from quantum communication to photonics. We have achieved large fractional delay for slow and stored light in Rb vapor using temporally-shaped control fields. Combined with amplification provided by selfrotation, we can produce slow and stored light pulses with large fractional delay and minimal distortion or attenuation.

K1.00072 Coherent quantum optical control with sub-wavelength resolution, ALEXEY GORSHKOV, MIKHAIL LUKIN, Physics Department, Harvard University, Cambridge, MA — We propose a new method for coherent optical far-field manipulation of quantum systems with resolution that is not limited by the wavelength of radiation. Our method makes use of the manipulation of atomic response with a control beam under the conditions of Electromagnetically Induced Transparency. The idea is that within a small distance Δr around a zero of a strong control field (e.g. a standing wave or a beam with a doughnut-like cross section) an atom will not be saturated, but it will be saturated outside of Δr, where Δr can be made arbitrarily small by increasing the power of the control field. As a result, two atoms can respond very differently to the control field or other simultaneously applied fields despite being separated by much less than a wavelength. This approach can be used for selective coherent manipulation of proximally spaced ions, atoms, or solid-state defects. Practical performance of this technique and its potential applications to quantum information processing are discussed.

K1.00073 Cold Atoms inside a Hollow-Core Photonic-Crystal Fiber, VLATKO BALIC, MICHAL BAJCSY, Harvard University, ALEXANDER ZIBROW, Harvard University, Lebedev Institute of Physics, RAS, VLADAN VULETIC, MIT, MIKHAIL LUKIN, Harvard University — Cold atoms confined inside a hollow-core photonic-crystal fiber with core diameters of a few photon wavelengths are a promising medium for studying nonlinear optical interactions at extremely low light levels. The high electric field intensity per photon, large optical depths, and interaction lengths not limited by diffraction are some of the unique features of this system. We describe recent progress in our experiment that uses a combination of magnetic trapping and a red-detuned optical dipole trap to transfer cold Rb87 atoms into the hollow-core fiber. We present data on transfer efficiencies as well as preliminary experiments towards nonlinear optics with few-photon pulses.

K1.00074 ATOMIC & MOLECULAR SPECTROSCOPY –

K1.00075 Atomic transitions among the levels of 3d7, 3d74s, 3d74p configurations in Fe III, NARAYAN C. DEB, ALAN HIBBERT, Queen’s University Belfast — We present a configuration interaction (CI) calculation for the fine-structure levels of Fe III belonging to 3d7, 3d74s and 3d74p configurations. All 136 LS states of these three configurations are considered. Using Hartree-Fock functions for 1s, 2s, 2p, 3s, 3p and 3d we have generated further radial functions for 3s, 4p, 4d, 4f, 5s, 5p, 5d, 5f and 6p orbitals. 4s and 4p orbitals are taken as spectroscopic and remaining orbitals taken as either correction or correlation orbitals. Relativistic effects are accounted for through Mass correction and Darwin terms in addition to an approximate form of the two-body spin-orbit interaction term. Ab initio fine-structure levels are then fine-tuned to bring them in line with the available NIST values. We then calculate the oscillator strengths and transition probabilities for all possible E1 transitions. CIV3 program of Hibbert [Comp. Phys. Comm. 9 141 (1975)] has been used for the present calculation. The results will be presented at the conference.

3This work is supported by the PPARC, UK through the Rolling Grant Grant PP/D00103X/1.

K1.00076 Energy Levels and Radiative Rates in Al-Like Copper, G.P. GUPTA, S.D. (Postgraduate) College, INDIA, A.Z. MSEZANE, Clark Atlanta U. — Excitation energies from ground state for 98 fine-structure levels and oscillator strengths and radiative decay rates for all electric-dipole-allowed and intercombination transitions among the fine-structure levels of the terms belonging to the (1s2s2sp5)3s3p, 3s3p5, 3s3d5, 3s3p3d, 3s4d, 3s4f, and 3s3p4s configurations of Cu XVII, are calculated using extensive CI wave functions [1]. The important relativistic effects in intermediate coupling are incorporated through the Breit-Pauli Hamiltonian. We have also investigated the effects of electron correlations on our calculated data, particularly on the intercombination transitions, by including orbitals with up to n=5, considering up to three electron excitations from the valence electrons of the basic configurations and including a large number of configurations. Our adjusted excitation energies are in excellent agreement with experimental results [2]. We find enormous mixing among several fine-structure levels, making it very difficult to identify them correctly. Our radiative lifetimes of the fine-structure levels agree excellently with those of Ref. [3]. 1. A. Hibbert, Comput. Phys. Comm. 9, 141 (1975). 2. T. Shirai et al., J. Phys. Chem. Ref. Data 20, 12 (1991). 3. E. Trabert et al., J. Opt. Soc. Am. B 5, 2175 (1988)

1A.Z.M. is supported by DOE, Div. of Chemical Sciences, OBES, OER.
K1.00077 Hyperfine-induced 2s2p33P0 – 2s21S0 transition in Be-like ions1. K.T. CHENG, M.H. CHEN, Lawrence Livermore National Laboratory — The hyperfine-induced 2s2p33P0 – 2s21S0 transition rate for Be-like 47Ti+4 is recently measured in a storage-ring experiment by Schippers et al. [Phys.Rev.Lett. 98, 033001 (2007)]. The measured value of 0.56(3) s−1 is almost 60% larger than the multiconfiguration Dirac-Fock value of 0.356 s−1 by Marques et al.[Phys. Rev. A 47, 929 (1993)]. In this work, we use a large-scale relativistic configuration-interaction method to calculate this hyperfine-induced rate. Coherent hyperfine-quenching effects between the 2s2p33P1 and 13P1 states are included in a radiation damping formalism. Contrary to the findings of Marques et al., contributions from the 13P1 state are substantial and lead to much better agreement with experiment. 1This work was performed under the auspices of the U.S. DOE by the University of California, Lawrence Livermore National Laboratory under contract No. W-7405-ENG-48.

K1.00078 Dependence of Ramsey fringe width on parameters. JAMES SUPPLEE, Drew U. and Stevens Tech., PAUL-MICHAEL HUSEMAN, Drew U. — A Ramsey pulse pair (two coherent pulses separated in time) clearly has much longer duration than either pulse would have by itself. This gives the Ramsey pair a narrower energy spectrum than the single pulse and therefore a fundamental spectroscopic advantage in resolution. Even if one uses a single “long-type” pulse (duration equal to that of the entire Ramsey pair including dark time) instead, the Ramsey pair spectrum can still be narrower. Under a broad range of circumstances, the central peak of the Ramsey pair’s spectrum is only about 0.6 times as broad as that of a single long-type pulse. This “narrowing factor” of 0.6 does not always carry over directly to a comparison of peak widths as measured by population inversion. We will present results of calculations that explore how this narrowing factor (Ramsey versus single long-type pulse) depends on parameters such as pulse duration, dark time, and atomic inversion.

K1.00079 Branching Ratios for Hydrogenic Zeeman States from Classical Mechanics1. MICHAEL W. HORBATSCH, ERIC A. HESSELS, MARKO HORBATSCH, York University, Toronto, Canada — In previous work we applied the classical Larmor radiation formula to calculate the lifetimes of hydrogenic Zeeman levels on the basis of classical mechanics and semi-classical quantization [1]. For the field-free case excellent agreement with quantum mechanics was obtained for total lifetimes, and good agreement for branching ratios [2]. In this work we report on (semi-)classical results for the branching ratios of Zeeman levels based on Hamilton-Jacobi perturbation theory. The branching ratios are calculated using numerical solutions of the trajectories and their Fourier analysis. While the agreement is good for partially summed branching ratios, some discrepancies with quantum results are found at the level of the full branching ratios. [1] Phys. Rev. A 72, 033405 (2005) [2] Phys. Rev. A 71, 020501(R) (2005).

K1.00080 Core excitation effects on oscillator strengths for transitions in four electron atomic systems1. T. N. CHANG, USC, Los Angeles, CA and NCTS, Hsinchu, Taiwan, YUXIANG LUO, USC, Los Angeles, CA — By including explicitly the electronic configurations with two and three simultaneously excited electronic orbital, we have extended the BSCI (B-spline based configuration interaction) method [1] to estimate directly the effect of inner shell core excitation to oscillator strengths for transitions in four-electron atomic systems. We will present explicitly the changes in the oscillator strengths due to core excitation, especially for transitions involving doubly excited states and those with very small oscillator strengths. The length and velocity results are typically in agreement better than 1% and less. [1] Tu-nan Chang, in Many-body Theory of Atomic Structure and Photoionization, edited by T. N. Chang (World Scientific, Singapore, 1993), p. 213-47; and T. N. Chang and T.K. Fang, Elsevier Radiation Physics and Chemistry 70, 173-190 (2004).

K1.00081 Relativistic many-body calculations of lifetimes, rates, and line strengths of multipole transitions between 3l′−14l′ states in Ni-like ions1. U.I. SAFRONOVA, A.S. SAFRONOVA, University of Nevada, Reno, P. BEIERSDORFER, Lawrence Livermore National Laboratory — Transition rates and line strengths are calculated for electric-multipole (E1, E2, and E3) and magnetic-multipole (M1, M2, and M3) transitions between 3s3p6d3l′4d4l, 3s3p6d3l′4f4l, and 3s3p6d3l′4f4l states (with l′ = 4l, 4l+1, 4l+2, and 4l+3) in Ni-like ions with the nuclear charges ranging from Z = 34 to 100. Relativistic many-body perturbation theory (RMBPT), including the Breit interaction, is used to evaluate retarded multipole matrix elements. Transition energies used in the calculation of line strengths and transition rates are from second-order RMBPT. Lifetimes of the 3s3p6d3l′4s and 3s3p6d3l′4d states are given for Z = 34–100. Taking into account that calculations were performed in a very broad range of Z, the most of the data are presented in graphs as Z-dependences. The full set of data is given only for Ni-like Mo and W ions. These atomic data are important in modeling of M-shell radiation spectra of heavy ions generated in electron beam ion trap experiments and for fusion research. 1This project is supported in part by grant no. NSC 95-2119-M-007-001 in Taiwan.

K1.00082 Correlation and relativistic effects for the 4d – nl multipole transitions in Pd-like ions. R. BISTA, R. BRUCH, U.I. SAFRONOVA, University of Nevada, Reno, H. MERABET, Dhoraf University — Wavelengths, transition rates, and line strengths are calculated for the 85 possible multipole (E1, M1, E2, M2, E3, M3) transitions between the excited 4p64d4f, 4p64d5f, 4p64d10f, and 4p63d10f states and the ground 4p64d10 state in Pd-like ions with the nuclear charges ranging from Z = 47 to 100. Relativistic many-body perturbation theory (RMBPT), including the Breit interaction, is used to evaluate line strengths and transition rates for multipole transitions in hole-particle systems. This method is based on the relativistic many-body perturbation theory, agrees with MCDF calculations in lowest-order, includes all second-order correlation corrections, and includes corrections from negative energy states. The calculations start from a [Zn]4p64d10 Dirac-Fock potential. First-order perturbation theory is used to obtain intermediate-coupling coefficients, and second-order RMBPT is used to determine the matrix elements. The contributions from negative-energy states are included into the second-order E1, M1, E2, M2, E3, and M3 matrix elements. The resulting transition energies and transition rates are compared with experimental values and with results from other recent calculations. The Z dependence of the energy splitting for all triplet terms of the 4p64d4f and 4p64d5f configurations are shown for Z = 47–100.

Work was supported by NNSA under DOE Cooperative Agreement DE-FG52-06NA27588. Work at LLNL was performed under auspices of the DOE under contract No. W-7405-Eng-48.
K1.00083 Spectral Analysis of Hydrogenic Ions Embedded in Strongly Coupled Plasmas†, YEW KAM HO, H.F. LAI, Y.C. LIN, Institute of Atomic and Molecular Sciences, Academia Sinica, Taipei, Taiwan, ROC — In the present work, we report theoretical calculations for spectral properties of hydrogenic ions He\(^{+}\), Li\(^{2+}\), Be\(^{3+}\), B\(^{4+}\), and C\(^{5+}\) embedded in strongly coupled plasmas. The hydrogenic 1s, 2p, and 3p states have been investigated using the ion-sphere (IS) model [1]. The spectral properties including the ground state energy, the excitation energy, and the oscillator strength for the 1s \(\rightarrow\) 2p and 1s \(\rightarrow\) 3p transitions are calculated using B-spline basis. Results have been obtained as functions of the ion-sphere radius R in the IS model. Our calculated values can be used to deduce the temperature and the electronic charge density for strongly coupled plasmas. A comparison with an earlier calculation [2] will be presented at the meeting.


†This work is supported in part by NSC of Taiwan.

K1.00084 The Seventh and Eighth Spectra of Cerium (Ce VII and Ce VIII)†, TAUHEED AHMAD, Aligarh Muslim University, YOGI JOSHI, St. Francis Xavier University — The spectrum of cerium was recorded in the 2000 \(\rightarrow\) 350 Å wavelength region on a 3-m normal incidence spectrometer using triggered spark and sliding spark sources. The seventh and eight spectra of cerium have never been reported. Resonance lines in both spectra have been positively identified and the ground states for both spectra have also been established. Below 500 Å there is an overlap of many spectra of different ions arising out of inner shell f-electron excitations and which has complicated the analyses. The latest stage of the analyses will be presented.

†Research supported by NSERC and StFXU

K1.00085 Absolute Wavelength Measurements of Transitions in H- and He-like Argon and Sulfur Ions with a Novel Crystal Spectrometer, HJALMAR BRUNHS†, JOHANNES BRAUN, KATHARINA KUBIČEK, JOSÉ R. CRESPO LOPEZ-URRUTIA, JOACHIM ULLRICH, Max Planck Institute for Nuclear Physics, Heidelberg, Germany, STRUCTURE AND DYNAMICS OF FEW-ELECTRON IONS (EBIT) TEAM — High-precision absolute and relative wavelength measurements of highly charged H-like and He-like ions have been carried out at the Heidelberg Electron Beam Ion Trap (EBIT) with a novel crystal spectrometer applying the Bond method. The Ar\(^{26+}\) results, with error bars of \(\delta\lambda/\lambda < 5 \times 10^{-6}\), are the most precise absolute wavelength measurements in highly charged ions up to now and confirm recent relativistic and QED calculations for this range of Z. This level of accuracy was reached by introducing a new method for the determination of the Bragg angle using two laser beams as fiducials. These make the commonly-used entrance slits unnecessary, thus reducing the time necessary for reaching high statistical significance, and also eliminating various systematic geometric error sources. A comparison to theory and other experimental results will be presented.

†current affiliation: Columbia Astrophysics Laboratory

K1.00086 Comparison of the Dependence of Saturated Absorption Spectra of 87Rb D2 line on the Beam Size and the Intensity, HEUNG-ROYOL NOH, GEOL MOON, HUY DIEP DO, Department of Physics and Institute of Opto- Electronic Science and Technology, Chonnam National University — We measure the saturated absorption spectra of the 87Rb D\(_2\) line by varying the size and the intensity of the pump beam. We found that the increase of the beam size is almost equivalent to the increase of the pump laser intensity. This is because both the beam size and intensity influence the interaction of atoms with the pump laser beam, and especially the variation of the beam size means the variation of the transit time of atoms crossing the beam cross-section. However, we found that there exits difference for the signal of closed transition line. This can be explained by the saturation effect. We compared the experimental results with the theoretical calculations based on the rate equation model, and found good agreement between them.

K1.00087 Revised Analysis and Configuration Interaction in Mo VI, JOSEPH READER, NIST — Mo VI, with ground term 4p\(^{6}\)4d\(^{2}\)2D, has a simple one-electron spectrum 4p\(^{n}\)nl-4p\(^{n}\)n’l’ as well as a more complex spectrum arising from inner-shell excitations 4p\(^{n}\)4d\(^{2}\) and 4p\(^{n}\)4d\(^{4}\)5s\(^{2}\). A few years ago we observed the spectrum of Mo VI from 200 to 5300 Å with a sliding-spark and the 10.7-m normal- and grazing-incidence spectrometers at NIST. We revised a number of the known even levels of the one-electron spectrum [1] and confirmed the ionization limit [1], which was based largely on the Penning discharge observations of Romanov and Striganov [2]. A number of Romanov and Striganov’s line identifications were also revised. Our results have not yet been published. More recently we revisited the 4p\(^{n}\)4d\(^{2}\) transitions and revised several of the core-excited levels [3]. Some levels of 4p\(^{n}\)4d\(^{2}\) are highly mixed with one-electron levels, resulting in transitions at longer wavelengths between 4p\(^{n}\)4d\(^{2}\) and one-electron levels. This provides accurate connections between the ground term and some highly-excited levels and thus highly accurate Ritz-type wavelength predictions for resonance transitions. Improved values have been obtained for all of the energy levels and a new least-squares fit for the odd configurations carried out. [1] B. Edlén et al., Phys. Scr. 32, 215 (1985). [2] N. P. Romanov and A. R. Striganov, Opt. Spectros. (USSR) 27, 8 (1969). [3] A. Kancerevicius et al., Lith. Phys. J. 31,143 (1991). Supported by Office of Fusion Energy Sciences of D.O.E.

K1.00088 Optical transitions among Rydberg states—an ideal avenue for measuring both the fine structure and Rydberg constants accurately, JOSEPH TAN, PETER MOHR, National Institute of Standards & Technology — The fine structure and Rydberg constants play crucial roles in tests of QED and the Standard Model, in the International System of units (SI), and in the CODATA evaluation of fundamental constants. The extraordinary precision of femtosecond-laser frequency combs opens the possibility of directly measuring both the fine structure and Rydberg constants in an atomic system with high accuracy provided that the atomic system is engineered to be essentially free from poorly-understood complexities (such as nuclear structure). This new approach is attractive because optical frequency metrology has attained such high precision as to outpace the most detailed theory for even the simplest atom in nature, hydrogen. One avenue to explore involves the synthesis of hydrogen-like ions in special high-orbital states engineered to make them better suited for measuring these two constants. In particular, the fine structure splitting would be magnified by a large nuclear charge Z, which is selected so that the measurements—transitions among these high orbital states—are in the domain of optical frequency combs. Progress in assessing the QED corrections to the Dirac theory for \(^{20}\)Ne\(^{8+}\) as a test case is discussed. The advantages and challenges in realizing this new approach for accurately measuring both the fine structure and Rydberg constants are presented.
K1.00089 Determining the cesium \(7d^2D_j\) hyperfine structure using two-photon resonant spectroscopy of a thermal beam\(^1\), ANDREW KORTYNA, VICTOR FIORE, Lafayette College — The hyperfine structures of the \(7d^2D_{3/2}\) and \(7d^2D_{5/2}\) states of \(^{133}\)Cs are determined through two-photon, laser-induced-fluorescence spectroscopy of a thermal beam. Two single-mode external-cavity diode lasers provide narrow bandwidth radiation for resonant two-step excitation of the \(7d^2D_j\) states. A servo-feedback circuit locks one laser to the \(6S_{1/2}(F) \rightarrow 6P_{3/2}(F')\) hyperfine transitions. Optical pumping of the ground hyperfine manifold is minimized by phase modulating this laser at 9.193 GHz. The second laser is scanned over the \(6P_{3/2}(F') \rightarrow 7d^2D_j(F'')\) transitions. Using various combinations of the ground and intermediate hyperfine levels (i.e., \(F\) and \(F''\)), all hyperfine intervals of the \(7d^2D_j\) states are observed. The scanned laser’s relative frequency is calibrated through phase modulation; the resulting sidebands cause atomic features to be repeated at precise intervals. High accuracy is achieved by directly referencing the modulation frequency to the \(\Delta^7\)Rb \(5s^2S_{1/2}(F = 1) \rightarrow 5s^2D_{1/2}(F = 2)\) ground state hyperfine transition using an atomic frequency standard.

\(^1\)Supported by Lafayette College and NSF.

K1.00090 Autoionizing Rydberg series in argon\(^1\), R.L. BROOKS, B.M. VAN DER ENDE\(^2\), C. WINSLADE, Guelph-Waterloo Physics Institute, R.H. DELAAT, N.P.C. WESTWOOD, Guelph-Waterloo Centre for Graduate Work in Chemistry — Optical transitions from two microwave discharge excited states of argon have been observed using cavity ring-down spectroscopy. The two originate on the high lying levels, \(3d[3/2]_2\) and \(3d[1/2]_1\) and terminate on the \(n''f[5/2]_2\) Rydberg (\(n = 8\) to 22) levels which, except for \(n = 8\), lie between the \(2P_{3/2}\) and \(2P_{1/2}\) ionization thresholds. In total 24 spectral lines have been observed. The quantum defect has been measured to significantly higher precision than previously and agrees with previous values. Our determination of the \(2P_{1/2}\) series limit also agrees with previous measurements signifying that Stark shifts (and presumably Stark broadening) are not expected to be significant. The line widths, however, are broad and increase monotonically with \(n\) (above 9) for reasons that are not entirely clear. We observe a nearly three-fold jump in linewidth in going from \(n = 8\) to \(n = 9\), below and above the \(2P_{3/2}\) threshold, respectively. We propose that collisional broadening is the dominant mechanism but that electric field enhanced autoionization may also play a role.

\(^1\)Supported by the Natural Sciences and Engineering Research Council (NSERC) of Canada

K1.00091 Magnetic Resonance Reversals in Optically Pumped Alkali-Metal Vapor\(^1\), FEI GONG, YUAN-YU JAU, WILLIAM HAPPER, Princeton University — We report an unusual new phenomenon, peculiar sign reversals of the ground-state magnetic resonances and of the “zero-dip” resonance (Zeeman resonance at zero field) of optically-pumped, alkali-metal vapors. These anomalies occur when a “weak” circular polarized D1 laser light is tuned to pump atoms predominantly from the lower ground-state hyperfine multiplet. One can understand the signal reversals in simple, semi-quantitative way with reference to this distribution. Quantitative computer simulations are in excellent agreement with observations.

\(^1\)Air Force Office of Scientific Research, Defense Advanced Projects Agency

K1.00092 Two Photon Spectroscopy of Rubidium Using a Grating-Feedback Diode Laser, SHANNON MAYER, ABRAHAM OLSON, EVAN CARLSON, University of Portland — We describe an experiment for investigating the 5S 1/2 to 5D 5/2 two-photon transition in rubidium using a grating-feedback diode laser operating at 778.1 nm. Tuning of the laser frequency over 4 GHz allows for the clear resolution of the Doppler-free spectral features and accurate measurement of the hyperfine ground-state splitting. A direct comparison between Doppler-broadened and Doppler-free spectral features is possible because both are distinctly evident in the spectra. By modifying the polarization state of the two laser fields, the impact of electric dipole selection rules on the spectra is investigated. This experiment is a valuable addition to the advanced laboratory; it uses much of the same equipment as the single-photon saturated absorption spectroscopy experiment performed on the 5S 1/2 to SP 3/2 transition in rubidium at 780.24 nm and provides students with an opportunity to investigate characteristics of atomic spectra not evident in the single-photon experiment. Moreover, rubidium two-photon transitions are of interest as new optical frequency standards due to their transition wavelength and narrow linewidth.

K1.00093 Temporal Photon Correlations and Two-Photon Absorption in Alkali Metals, DANIEL BENNETT, BRIAN SPECTOR, KYLE FOSTER, JOHN CARAHER, DePauw University — Virtual-state spectroscopy\(^1\) (VSS) is a proposal to use temporal correlations between photons as a probe of the eigenstate composition of the virtual state involved in a two-photon absorption process. The technique relies upon measuring modulations in the two-photon absorption cross section as “entanglement time” and imposed delays vary on a femtosecond scale. Photon pairs produced via parametric downconversion are the basis for these experiments. We report studies of the constraints on observing these effects in Na and Rb. This work involves computer simulations of VSS for the \(3s - 4s\) transition in Na and the \(5s - 5d\) transition in Rb with the goal of establishing the parameters required for a successful experimental test. We also report on parallel laboratory investigations in support of this goal. \(^1\)B.E.A. Saleh, B.M. Jost, H. B. Fei, M.C. Teich, Phys. Rev. Lett., 80 3483 (1998)

K1.00094 Precision Lifetime Measurement of the Cesium 6P3/2 State, B.M. PATTERSON, T. EHRENREICH, R.J. KNIZE, United States Air Force Academy — We have refined our atomic lifetime measurement technique\(^1\) and report a precision value for the 6P3/2 state of cesium. A single pulse (\(\sim nJ\)) from a mode-locked Ti:Sapphire laser excites atoms in counter-propagating thermal beams to the 6P3/2 state. A subsequent laser pulse is amplified using a regenerative amplifier to a few \(\mu J\) and is frequency-doubled, and ionizes atoms in the excited state. The ions are collected using a channel electron multiplier and counted. The measurement is repeated using excitation and detection pulses that are increasingly separated in time, allowing the decay from the excited state to be determined. Our analysis indicates a lifetime of 30.44 ns with a statistical uncertainty of 0.02 ns. We will discuss improvements in our apparatus and address the dominant systematic effects. These include (1) the effects of imperfect extinction ratio of the electro-optic modulators used for laser pulse selection; (2) the effects of atoms moving through spatially non-uniform laser beams; and (3) the effects of misalignment of the excitation and ionization laser beams.

K1.00095 Progress on single indium ion and single barium ion frequency references. WILLIAM TRIMBLE, JEFF SHERMAN, ADAM KLECZEWSKI, WARREN NAGOUREN, NORVÁL FORTSON. University of Washington — Energy levels in laser cooled trapped ions are attractive as optical frequency standards because they can be made free of many external perturbations. We report continued development of single indium ion and barium ion rf Paul-Straubel traps and laser cooling systems. In In⁺, the forbidden 1S₀ → 3P₀ transition at 237 nm has a quality factor of 10^{15} and is immune to DC quadratic Stark shifts. In Ba⁺, the τ~80 s gives the electric dipole forbidden 2051 nm 6S₁/₂ → 5D₃/₂ transition a quality factor of 10^{16}. Further, by choosing the transition 6S₁/₂(F' = 2, m = 0) → 5D₃/₂(F' = 0, m' = 0) transition in ¹³Ba⁺ (I = 3/2), the first order DC quadrupole Stark shift and 2nd order Zeeman shifts can be made to vanish. We present our latest experimental probes of these transitions using diode pumped solid state laser systems (a frequency quadrupled non-planar ring oscillator Nd:YAG at 946 nm and a diode pumped Tm:Ho:YLF at 2 μm) stabilized to vertically-mounted ULE reference cavities.

K1.00096 Laser spectroscopy with lithium atoms in an undergraduate lab. TORY CARR, YANCEY SECHREST, SCOTT WAITUKAITIS, ALEX CRÓNIN. University of Arizona — We present highlights from an undergraduate laboratory using 671 nm diode lasers to study spectra of lithium atoms. Faraday rotation spectra, the Hanle effect, atom beam deflection, and saturation absorption spectra are demonstrated. We also describe how the extended cavity diode lasers and heat-pipe lithium vapor cells were constructed.

K1.00097 Molecular Conformation of Optically Active Five and Six- Membered-Ring Ketones. WATHEQ AL-BASHEER, The Hashemite University, Zarqa 13115, Jordan, RICHARD PAGNI, ROBERT COMPTON. The University of Tennessee, Knoxville — Conformational analysis of chiral five and six-membered ring ketones will be presented. Electronic circular dichroism (CD) and vibrational circular dichroism (VCD) spectra for both R- and S- enantiomers of optically active carvine (C₆H₁₄O) exhibit marked temperature dependences. Theoretical calculations, using density functional theory (B3LYP with aug-cc-pVQZ basis set), show an equal magnitude but opposite sign for the CD and VCD for the two conformers of each R- and S- enantiomer. The Temperature dependent circular dichroism (CD) measurements of B(‘)-3-methylcyclopentanone 3MCP and carvone in 36 different common solvents is being employed to determine the conformers energy between the equatorial methyl and axial methyl of 3MCP and carvone. The results will be compared to the CD in the gas phase, solvent effect on optical rotation of 3MCP and carvone will be demonstrated and supported by DFT calculations. Temperature dependent vibrational Raman spectroscopy in the C-H stretch region is used to study conformation over a wide range of temperature (-15-135 °C) and at liquid nitrogen temperature. Temperature dependent variations of CD and Raman spectra are shown to be a useful technique to study the conformer’s populations and energy difference.

K1.00098 Fiber-Bragg-grating stabilized diode laser at 1450 nm locked to a high finesse build-up cavity. THOMAS DEVORE, MATTHEW REDSHAW, EDMUND MYERS. Florida State University — Using Doppler-tuned fast-beam laser spectroscopy and a high finesse build-up cavity (F ~60,000) excited by a 1319 nm Nd:YAG laser we previously measured the 1s2s ¹S₀ → 1s2p ¹P₁ intercombination interval in Si^{12+} to be 7230.5(2) cm⁻¹ [1]. The precision was limited by uncertainty in the (ν/c ~ 5%) ion beam velocity. An order of magnitude higher precision would provide a clear test of calculations of QED contributions in two-electron ions. We aim to attain this by alternately exciting the resonance with co- and counter-propagating laser beams using a cavity that has high-finesse for both 1319 nm and 1450 nm. For the 1450 nm wavelength we are using few-hundred mW, fiber-coupled, pump laser diodes that have been spliced to custom fiber-Bragg-gratings to achieve single-mode operation and greatly reduced linewidth [2]. The lock to the build-up cavity is achieved using the Pound-Drever-Hall technique with feedback to the laser diode current and to a piezo that strains the fiber between the laser and the FBG. The assistance of A. Khademian and D. Shiner (Univ. North Texas) is gratefully acknowledged. [1] M. Redshaw and E.G. Myers, PRL 88 023002 (2002). [2] A. Khademian and D. Shiner, BAPS 51, 145 (2006).

K1.00099 ULTRACOLD MATTER II

K1.00100 A Diode Laser System for the Trapping of Fermionic ⁶Li¹, C. WELFORD, D. DRIES, M. JUNKER, J. HITCHCOCK, Y.P. CHEN, R.G. HULET. Rice University Physics and Astronomy Department — We have built an all-diode system for confining ⁶Li in a MOT. A single 45 mW Mitsubishi diode in an extended cavity is locked to the 2 ²S₁/₂, F = 3/2 → 2 ²P₃/₂, F = 5/2 transition (D2) and seeds a 45 mW slave laser which provides the trapping light. Two additional 45 mW master-slave pairs which are frequency offset locked to the first laser provide the repump (on the D1 transition) and Zeeman slowing light. This laser system has been added to our existing apparatus which now produces BECs of ⁶Li. Evaporation of the bosonic ⁶Li sympathetically cools the ⁶Li in a magnetic trap, prior to transfer to an optical trap/lattice. This system will allow us to simulate quantum many-body phenomena that arise in condensed matter systems.

K1.00101 Superfluorescence from Laser-Cooled Atoms¹. E. PARADIS, B. BARRETT, A. KUMARAKRISHNAN. York University, R. ZHANG, G. RAITHHEL. University of Michigan — We have observed temporally resolved superfluorescence (SF) from samples of laser-cooled Rubidium atoms. The atomic system was excited to the 5D level from the ground state by a two-photon process, involving excitation laser pulses tuned to the vicinity of the 5S-5P and 5P-5D transitions. We observe time-delayed signals on the 6P-5S transition at 420nm. The delay time of these pulses is being employed to determine the conformers energy between the equatorial methyl and axial methyl of 3MCP and carvone. The results will be compared to the CD in the gas phase, solvent effect on optical rotation of 3MCP and carvone will be demonstrated and supported by DFT calculations. Temperature dependent vibrational Raman spectroscopy in the C-H stretch region is used to study conformation over a wide range of temperature (-15-135 °C) and at liquid nitrogen temperature. Temperature dependent variations of CD and Raman spectra are shown to be a useful technique to study the conformer’s populations and energy difference.

¹ Supported by NSF, ONR, and the Welch and Keck Foundations.

K1.00102 Experimental Progress in Laser-Cooling Molecules¹. MICHAEL DI ROSA, ALEXEI TONYUSHKIN, Los Alamos National Laboratory — At Los Alamos National Laboratory, we are studying a particular class of diatomics – the alkaline-earth monohydrides (e.g. BeH and CaH) – that have Rydberg transitions similar to the ²P₁/₂, ³/₂ → ²S₁/₂, ½ transitions of alkali atoms and appear suited to laser cooling. As a class, the A → X transitions of the alkaline-earth monohydrides possess characteristics that are favorable for Doppler-cooling, including a (nearly) diagonal Franck-Condon array and good spectral isolation of the transitions that form the cooling cycle. We will show how a beam of such molecules can be laser cooled and report the status of our experiments for the particular case of CaH.

¹ Los Alamos National Laboratory LDRD, Army Research Office
K1.00103 Development of a Quantum Gravity Gradiometer for Gravity Measurement from Space, JAMES KELLOGG, NAM YU, JAMES KOHEL, ROB THOMPSON, DAVE AVELINE, ERIKA D’AMBROSIO, LUTE MALEKI, Jet Propulsion Lab — Recent progress in cold atom interferometry has provided a new technique for sensitive inertial sensing. We are developing a mobile quantum gravity gradiometer for gravity field mapping using cold atom interferometers and employing component technologies suitable for a future flight instrument. We report on recent progress in the development of this gravity gradiometer, as well as results from related studies of coherence effects in atom-wave interferometers.

K1.00104 Dynamics of OH in a magneto-electrostatic trap, MANUEL LARA, BENJAMIN LEV, BRIAN SAWYER, JUN YE, JOHN L. BÖHN, JILA/University of Colorado/NIST — OH molecules resulting from Stark deceleration have been recently confined in a magnetic quadrupole trap. An electric field can be simultaneously applied to the trap, significantly influencing its dynamics. We have modeled the potential energy that governs the dynamics of the molecules in such a “magneto-electrostatic” trap, using a complete effective molecular Hamiltonian for OH. We find, however, that the resulting trapping potential can also be easily understood and even semi-quantitatively reproduced using simple classical models. We also discuss the trap lifetime due to non-adiabatic transitions to untrapped states, i.e., the analog in this trap of Majorana transitions in a quadrupole magnetic trap.

1This work was supported by the NSF.

K1.00105 A new optical decelerator to make ultracold molecules, SUSUMU KUMA, CREST, DAISUKE ANDO, Kyoto University, MASAAKI TSUBOUCHI, TAKAMASA MOMOSE, The University of British Columbia — We propose a new method to decelerate molecules using a dipole force of intense IR radiation. We found that periodical switching of a standing wave in an IR cavity decelerate molecules very efficiently. Numerical simulations showed large phase- space areas of decelerated molecules by this technique. An experimental setup to make ultracold molecules from the room temperature will be proposed.

K1.00106 Experimental Progress Towards the Development of Neutral Atom Quantum Computing Architecture Based on 2D Optical Lattices on a Chip, RAJANI AYACHITULA, ANDREW MORSS, GREG LAFYATIS, Ohio State University, KATHARINA GILLEN-CHRISTANDL, California Polytechnic State University, San Luis Obispo — Previously, we showed, theoretically, that optical lattices can be created above an optical cavity by destructively interfering laser light in two different waveguide modes. [1] Single atoms can be tightly trapped at the nodes of a lattice and can serve as individually addressable qubits of a quantum memory. We have also examined moving the atoms within the lattice. We have studied ways to realize one- and two-qubit gates. On the experimental side, we have developed and characterized optical waveguides suitable for making these optical lattices. We measure losses ≤1db/cm for TE0 and TE1 modes. To address individual modes we couple light into the waveguide modes using gratings fabricated on the waveguide surface. We have observed >15% coupling efficiency. Our initial scientific studies will characterize samples of cold atoms dropped onto the waveguide. We will discuss recent experimental progress. 1. Phys. Rev. A 70 032302 (2004)

K1.00107 Bose-Fermi-Hubbard-Model in the limit of large fermionic hopping an effective theory, ALEXANDER MERING, MICHAEL FLEISCHHAUER, Technical University of Kaiserslautern — We present calculations for the Bose-Fermi-Hubbard model in the limit of large fermionic hopping. Using the Born-Oppenheimer and the Markov-approximation leads to an effective hamiltonian for the bosons. This hamiltonian describes an infinite range extended Bose-Hubbard model with a long range density-density coupling which oscillates with a period that depends on the fermionic density. The resulting phase diagram consists of several different phases which will be analytically discussed and compared to numerical results obtained by exact diagonalization and DMRG methods.

K1.00108 Two bosonic dipoles under elongated confinement, KRITTIKA KANJILAL, Department of Physics and Astronomy, Washington State University, Pullman, WA 99164-2814 AND JILA, University of Colorado, Boulder, CO 80309-0440 — The behaviors of two particles under harmonic confinement strongly depend on the aspect ratio $\eta$, which is defined as the ratio between the trapping frequency along the $\rho$ and the $z$ directions. It has been shown that the properties of particles interacting through spherically symmetric potentials are, in the extreme limits of very large and very small $\eta$, well described by effective one- and two-dimensional Hamiltonian. This work considers two particles with anisotropic interactions confined in an elongated harmonic trap. Assuming that the dipole moments are aligned along the z-axis, we obtain the eigen spectrum of this system analytically and analyze how it changes as a function of $\eta$. To validate our analytical approach, we compare our results with the eigen spectrum obtained numerically for a short-range shape-dependent potential.

1We are supported by the NSF.

K1.00109 Time Evolution of Freely Expanded Bose-Einstein Condensates Containing Small Numbers of Atoms, DIAN-JIUAN HAN, DE-SHENG HONG, K.H. HUANG, National Chung Cheng University, TSIN-FU JIANG, National Chiao-Tung University — We investigate the time evolution of freely expanded Bose-Einstein condensates by measuring their aspect ratios at different times after releasing from a magnetic trap. In these measurements, the condensates contain no more than 9000 $^{87}$Rb atoms. By varying the trapping frequency and atom number, we measure the condensate aspect ratios at different expansion times in free space. We compare our measurements with that calculated from the Thomas-Fermi model and a direct numerical solution. Under our trapping condition, the data of the time dependent aspect ratios of the freely expanded condensates reasonably agree with the numerical calculations, but show clear deviation from the predictions by the Thomas-Fermi model when the atom number in the condensates is small.

K1.00110 Vortex formation during the growth of Bose-Einstein condensates, CHAD WEILER, TYLER NEELY, DAVID SCHERER, BRIAN ANDERSON, College of Optical Sciences, University of Arizona — We experimentally study the growth of Bose-Einstein condensates in harmonic trapping potentials with laser-induced perturbations to the potential well. We find that some time- independent perturbations can significantly impact the growth process and final state of the BEC. In particular, in numerical simulations and our experiments, we have observed the generation of vortices and vortex-antivortex pairs as a result of creating BECs in perturbed potentials. We will describe the results of our ongoing and completed experiments (D.R. Scherer, C.N. Weiler, T.W. Neely, B.P. Anderson, cond-mat/0610187, to be published in Phys. Rev. Lett.).
K.001111 Next-Order Analytic Wave Function for Correlated Confined Quantum Systems; Application to BEC
document. W. BLAKE LAING, MARTIN DUNN, DERRICK R. TOOTH, DEBORAH K. WATSON, University of Oklahoma — We have constructed the next-order correlated $N$-body wave function for an isotropic confined quantum system using a dimensional perturbation theory (DPT) approach. This additional perturbative order represents a significant advancement in our large-scale project of analytically describing beyond-mean-field effects in $N$-body systems using DPT. To solve this problem, we assemble a number of analytic building blocks within the DPT framework (such as “symmetry coordinates”, coupling products of irreducible representations, and a novel graph-theoretical technique). This method is well-suited for systems with “tunable” interactions because it makes no assumptions concerning the number of particles or the strength of inter-particle interactions. As an application, we report observable results for the density profile, excitation frequencies, and ground state energy of a fully correlated BEC in a harmonic trap.

1This work was supported by ARO.

K.001122 Spinor matter waves in optical lattices

TRISTRAM ALEXANDER, BEATA DABROWSKA-WUSTER, ELENA OSTROVSKAYA, YUVAL KIVSHAR, ARC Centre of Excellence for Quantum-Atom Optics, Nonlinear Physics Centre, RSPhysSE, The Australian National University, Canberra, Australia — We study, within the framework of the Gross-Pitaevskii model, nonlinear properties exhibited by a spinor $F=1$ Bose-Einstein condensate confined in a one-dimensional optical lattice. We show that the lattice modifies dynamical stability properties of both ferromagnetic and polar condensates with repulsive atomic interactions. This leads to modulational instability of three-component Bloch states of the spinor BEC at the edge of the first Brillouin zone regardless of the properties of the spinor ground state (ferromagnetic or polar). As a result, both ferromagnetic and polar-type nonlinearly localized states can coexist within the gap of the matter wave bandgap spectrum in the form of vector gap solitons with a small number of atoms and self-trapped gap waves containing a large number of atoms. We explore the variety of spatially localized states in the lattice potential and show that, in general, the localization properties and non-equilibrium dynamics of the spinor BEC in the lattice cannot be captured by the single-mode approximation, usually employed for the mean-field description of the spinor matter waves.

K.001113 Feshbach-stimulated Raman photoproduction of a Bose-Einstein condensate of singlet molecules

MATTHEW FENTY, Temple University, DANIELLE SAVAGE, MATT MACKIE, Temple University — We theoretically examine the formation of a quantum degenerate gas of stable singlet molecules via Feshbach-stimulated Raman photoproduction, or free-bound-bound-bound transitions from an atomic to a singlet molecular Bose-Einstein condensate. In particular, a magnetic field tuned near a Feshbach resonance initiates collective conversion from an atomic condensate to a triplet molecular condensate, which is then converted by three-laser stimulated Raman adiabatic passage (STIRAP) to a stable singlet molecular condensate. Although population of the target singlet state is near-unit efficient, the population of an intermediate state is significant ($\sim 10^{-3}$), and large bound-bound Rabi couplings ($\sim 10$ GHz) are required to avoid losses.

K.001114 Effects of resonant coupling on the formation of ultracold $^{85}$Rb$_2$ molecules

H.K. PECHKIS, D. WANG, Y. HUANG, E.E. EYLER, P.L. GOULD, W.C. STWALLEY, Physics Department, University of Connecticut, USA, CHRISTIANE P. KOCH, Freie Universit" at Berlin, Institut für Theoretische Physik, Germany — We have studied the effect of resonant electronic state coupling on the formation of ultracold ground-state $^{85}$Rb$_2$. The ultracold Rb$_2$ are formed by photoassociation (PA) to the $0^+_u$ state converging to the $5S + 5P_{1/2}$ limit, followed by radiative decay into high vibrational levels of the ground state, $X^1Σ_g^+$. The populations of high-$v$ levels of the $X$ state are monitored by resonance-enhanced two-photon ionization through the $2^3Σ^+_u$ state. We find that the populations of vibrational levels $v\approx 112-116$ are far larger than can be accounted for by the Frank-Condor factors for $0^+_g$–$X^1Σ_g^+$ transitions. Further, the ground-state molecule population exhibits oscillatory behavior as the PA laser is tuned through a succession of $0^+_g$ state vibrational levels. Both of these effects explained by a new calculation of transition amplitudes that includes the resonant character of the spin-orbit coupling of the two $0^+_g$ states converging to the $5P_{1/2}$ and $5P_{3/2}$ limits. The resulting enhancement of more deeply bound ground-state molecule formation will be useful for future experiments on ultracold molecules. We also present the progress toward forming $^{85}$Rb$_2$ by photoassociation in an optical dipole trap using a CO$_2$ laser. This work is supported by the NSF.

K.001132 Long-range Efimov states

JAVIER VON STECHER, Department of Physics and JILA, University of Colorado, Boulder, CO 80309 — We have identified a new class of Efimov states that appear in heteronuclear three-body systems where both intra- and inter-species interactions are resonant. Besides their peculiar symmetry, we speculate that such states should be truly universal. That is, their properties should only depend on the scattering lengths. These states’ long-range character forbids them to see the details of the interatomic interactions, which normally introduces an extra parameter into expressions relating to “ordinary” Efimov states. In the context of ultracold gases with tunable interactions, we thus believe that it is possible to predict precisely when such states should appear. Consequently, the observation of a single state would be enough to demonstrate the Efimov effect.

1Supported by the National Science Foundation.

K.001146 Analysis of strongly interacting few-body systems under external confinement

JAVIER VON STECHER, Department of Physics and JILA, University of Colorado, Boulder, Colorado 80309-0440, JOSE P. D’INCAO, JILA, University of Colorado, Boulder, Colorado 80309-0440, CHRIS H. GREENE, Department of Physics and JILA, University of Colorado, Boulder, Colorado 80309-0440 — We investigate the properties of three and four-body systems under external confinement interacting through a short-range model potential. Using a correlated gaussian basis set, we study the spectra as a function of the two-body scattering length for fermionic and bosonic systems. From these results we can extract the main properties of the hyperspherical effective potentials, which in turn dictates the main collisional aspects for such systems. We also investigate the existence of weakly bound four-body states and their relation with the Efimov physics.

1This work was supported in part by the National Science Foundation.

K.001126 Production and Trapping of Ultracold Polar Molecules

NATHAN GILFOY, ERIC HUDSON, Yale University Department of Physics, JEREMY SAGE, MIT Lincoln Laboratory, SUNIL SAINIS, Yale University Department of Mechanical Engineering, DAVID DEMILLE, Yale University Department of Physics — Recently we have demonstrated the production of a sample of ultracold, polar RbCs molecules in their absolute vibronic ground state. The sample has a translational temperature of 100 nK and a narrow distribution of rotational states. The molecules are initially formed from laser-cooled $^{85}$Rb and $^{133}$Cs atoms via photoassociation, resulting in short-lived, vibronically excited RbCs molecules. A fraction of these excited molecules subsequently spontaneously decay to ground electronic states, populating many excited vibrational levels. We then transfer the population of one of these levels, $1^1Σ^+$ ($v = 37$), to the absolute vibronic ground state via a pump-dump scheme. We discuss progress toward observing strong, anisotropic collisions between these molecules through trapping them using a quasi-electrostatic trap (QUEST). We will also discuss our progress in implementing a Stimulated Adiabatic Raman Passage scheme to improve the transfer process to the vibronic ground state.
**K1.00118 Experimental progress towards investigation of ultracold KCs molecules**

*Daniel Barker, Myrrha Andersen, Joseph Porémski, Marin Pichler, Goucher College* — We report on progress towards simultaneous cooling and trapping of K and Cs atoms with the objective to produce ultracold KCs molecules, for spectral investigation. Our systems consist of separate lasers for cooling and repumping transitions for both species and a simple locking scheme. We present the photoassociation and resonant multi-photon detection schemes, and discuss possible applications.

1Supported by Research Corporation and Goucher College

**K1.00119 Progress toward measuring fast atomic recombination in ultracold plasma**

*Michael Lim, Lucas Willis, Rowan University Department of Physics and Astronomy* — We report on progress toward measuring the time-dependent distribution of atomic energy levels populated by recombination and collisions in ultracold plasma. The plasma is produced by direct photo-ionization of rubidium atoms in a magneto-optical trap. Our primary goal is to measure the changing Rydberg atom distribution in the first microsecond after plasma creation. Although predictions have been made for system behavior in this interval, this type of measurement has been elusive. Our apparatus features fast deflector plates to prevent saturation of the multi-channel plate detector, which is one of the main technical obstacles in this effort.

2Support from Research Corporation CC6180 and NSF PHY-0613659

**K1.00120 All-Optical Production of Degenerate Fermi Gas toward Optical Lattice Experiments**

*Yasuhsa Inada, Taizo Miyato, The University of Tokyo, Shut'a Nakajima, Tokyo Institute of Technology, Makoto Kuwata-Gonokami, The University of Tokyo, Masahito Ueda, Japan Science and Technology Agency and Tokyo Institute of Technology, Takashi Mukaiyama, Japan Science and Technology Agency then has much in common with propagation of ultra-slow light. Applications of coherent scattering and remote sensing to the detection of bio and chemical pathogens (e.g., anthrax) via C- ray Spectroscopy, Marlan Scully, Texas A&M and Princeton Universities — In recent work we have demonstrated strong coherent backward wave oscillation using forward propagating fields only. This surprising result is achieved by applying laser fields to an ultra-dispersive medium to Nuclear Physics then has much in common with propagation of ultra-slow light. Applications of coherent scattering and remote sensing to the detection of bio and chemical pathogens (e.g., anthrax) via Coherent Anti-Raman Scattering together with Femtosecond Adaptive Spectroscopic Techniques (FAST CARS [Opt. Comm., 244, 423 (2005)]) will be discussed. Furthermore, the interplay between quantum optics (Dicke super and sub-radiant states) and nuclear physics (forward scattering of $\gamma$ radiation) provides interesting problems and insights into the quantum control of scattered light [PRL, 96, 010501 (2006)].

3Supported by NSF, ONR, and the Welch and Keck Foundations.


**Friday, June 8, 2007 8:00AM - 10:24AM –**

**Session N1 Herbert Walther Memorial Session**

**8:00AM N1.00001 QUANTUM CONTROL OF LIGHT: From Slow Light and FAST CARS to Nuclear $\gamma$-ray Spectroscopy**

*Marlan Scully, Texas A&M and Princeton Universities* — In recent work we have demonstrated strong coherent backward wave oscillation using forward propagating fields only. This surprising result is achieved by applying laser fields to an ultra-dispersive medium with proper chosen detunings to excite a molecular vibrational coherence that corresponds to a backward propagating wave [PRL, 97, 113001 (2006)]. The physics then has much in common with propagation of ultra-slow light. Applications of coherent scattering and remote sensing to the detection of bio and chemical pathogens (e.g., anthrax) via Coherent Anti-Raman Scattering together with Femtosecond Adaptive Spectroscopic Techniques (FAST CARS [Opt. Comm., 244, 423 (2005)]) will be discussed. Furthermore, the interplay between quantum optics (Dicke super and sub-radiant states) and nuclear physics (forward scattering of $\gamma$ radiation) provides interesting problems and insights into the quantum control of scattered light [PRL, 96, 010501 (2006)].

**8:36AM N1.00002 Cavity quantum electrodynamics: From one-asmer to single-photon server**

*Gerhard Rempe, Max-Planck Institute for Quantum Optics, Hans-Kopfermann Str. 1, D-85748 Garching, Germany* — The first experiment demonstrating strong coupling between single Rydberg atoms and single microwave photons was performed in Herbert Walther’s laboratory 20 years ago [G. Rempe, H. Walther, and N. Klein, Phys. Rev. Lett. 58, 353 (1987)]. At that time, investigation of light-matter interaction at the single-particle level was considered academic. Today, fundamentally new applications are on the horizon, in particular in the optical domain where laser cooling and trapping techniques for atoms can be implemented. New light forces have been discovered, enabling one to store atoms for such a long time that genuine quantum protocols can now be realized with just one single intracavity atom. A first example is the realization of a deterministic single-photon server with realtime control of its performance. A second experiment has achieved deterministic entanglement of an atom and a photon emitted from the cavity. Subsequent mapping of the atomic state onto a second photon makes possible to produce entangled photons on demand. Such novel experiments constitute important steps towards the production of highly entangled many-photon quantum states and scalable quantum networks of atom-cavity systems. The fascinating possibilities opened up by cavity quantum electrodynamics continue to keep the field young and exciting.
9:12AM N1.00003 Interactions of cold Rydberg atoms

GEORG RAITHEL, University of Michigan — Rydberg-atom clouds excited from cold atomic gases exhibit a rich variety of collision processes. A review of state-changing and ionizing collisions in these systems will be provided. I will then focus on the role of attractive / repulsive interatomic forces between Rydberg atoms. The effects of Rydberg-excitation blockades that result from these interactions will be discussed. I will also report on progress in experiments on the interaction of cold Rydberg atoms with modulated ponderomotive potentials. In the second part of the talk, advances in the laser-cooling and trapping of ground-state and Rydberg atoms in strong magnetic fields of several Tesla will be described. Collisions in cold, magnetized Rydberg-atom gases lead to the production of long-lived atoms in so-called drift states, also known as guiding-center states. In low-temperature collision-rich environments, such as in the cold Rydberg atom gases and plasmas studied in this work, they are quite abundant. Results on the trapping of such atoms in conservative potentials and on the evolution of Rydberg-atom gases in cold plasmas in strong magnetic fields will be presented.

3This work is supported by NSF and DoE.

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9:48AM N1.00004 Precision Experiments with Single Particles in Ion Traps for Tests of Fundamental Interactions

WOLFGANG QUINT, GSI — Ion trap technology has made it possible to store, cool and observe single ions or ensembles of few ions under well controlled experimental conditions and at very low temperatures [1]. Single particles in traps allow for clean investigations of basic interactions and also for the determination of fundamental constants. This has been demonstrated by investigations of Quantum Electrodynamics (QED) with respect to the g-factor of the free electron [2] and of the electron bound in hydrogen-like carbon and oxygen [3], which form the most precise determinations of the fine-structure constant and of the mass of the electron, respectively. A precision test of CPT invariance has been performed in a proton-antiproton mass comparison with single particles in a Penning trap [4]. Optical quantum jump spectroscopy with single laser-cooled ions in rf traps has paved the way for optical frequency standards and for the investigation of a possible variation of fundamental constants. With the novel technique of deceleration, trapping and cooling, even high-accuracy experiments with highly charged ions up to uranium U91+ will be possible at the HITRAP facility at GSI Darmstadt [5].


Friday, June 8, 2007 8:00AM - 10:24AM –
Session N2 Molecules in Strong Optical Fields TELUS Convention Centre Macleod C

8:00AM N2.00001 Photonic Reagents: Strong Field Laser Pulses for Controlling Chemical and Physical Processes

ROBERT LEVIS, Temple University — This presentation will focus on the latest developments in the area of using strong-field laser pulses to manipulate chemical systems in both the gas and condensed phase. The laser intensities are sufficient to alter the electronic Hamiltonian of a molecule or condensed phase system. In fact, the perturbations are on the order of the electronic level spacing between the ground and electronic states of any molecular system. This implies that anticipated chemical reactivity will be at least on the order of that induced by conventional reagents and enzymes. Strong field lasers are capable of inducing massive electron polarization and we now demonstrate that proton migration is also possible on the timescale of the laser pulse. In combination with laser pulse shaping methods and computer-based feedback control, strong field chemistry has initiated a plethora of new laser-chemistry experiments. Recent experiments involving the use of strong field chemistry to provide a novel, rapid, and selective sensing scheme will be discussed, as well as dimensionality reduction tools to predict and navigate the high dimensional search spaces. The use of adaptive feedback to control laser-induced filamentation in the solution phase will also be described.

8:36AM N2.00002 Angle Dependent Ionization of Small Molecules

PAUL CORKUM, National Research Council of Canada — The ionization probability and both the direct and re-scattered photoelectron momentum spectrum are all sensitive to the angle of a molecule with respect to the laser field. We experimentally measure the sensitivity of the ionization probability to molecular alignment using H₂, the simplest molecule as well as N₂, O₂, and CO₂. Concentrating on O₂ and N₂ we then demonstrate the natural quantum interference that occurs when the electron tunnels from perpendicularly aligned O₂, contrasting it with N₂. We show that the direct electrons preserve the symmetry of the orbital from which they tunnel, filtered through the momentum filter of the tunnel. Finally we show that the re-scattered electrons are also sensitive to molecular alignment, writing the molecular structure onto their angular distribution.


9:12AM N2.00003 Controlling the rotational motion of asymmetric top molecules by laser pulses

HENRIK STAPFELFELDT, Department of Chemistry, University of Aarhus — While the vast majority of previous studies on laser induced alignment of small molecules dealt with linear systems, interest is now shifting to asymmetric tops due to both the new physics involved and the broad range of applications. However, controlling the rotational motion of asymmetric tops represents, in general, a much harder task because they are characterized by three axes with different moments of inertia and different polarizability components. This talk will discuss recent studies on laser alignment of asymmetric tops. First, we show how the alignment dynamics induced by a single linearly polarized laser pulse can be controlled by the fluence. When the fluence is increased the complex non-periodic revival structure of an asymmetric top approaches a simple periodic rotation around a single axis. Second, we introduce a new method for 3-dimensional (3D) alignment control by combining two linearly polarized pulses laser pulses, one short and one long compared to the molecular rotational periods. The long pulse strongly aligns the most polarizable molecular axis along its polarization axis while the orthogonally polarized short pulse sets the molecule in to controlled rotation about the axis aligned. As a result strong 3D alignment occurs immediately after the short pulse and is repeated periodically reflecting the revolution about the axis aligned. Our method opens new directions for field-free 3D alignment and for controlling internal rotations of molecules.

9:48AM N2.00004 Non-perturbative Quantum Control via the Non-resonant Dynamic Stark Effect

ALBERT STOLOW, National Research Council — We will discuss Quantum control using the non-resonant Dynamic Stark Effect as a new and powerful tool. Dynamic Stark Control (DSC) applies to both molecular rotation and vibration. We show how DSC, which uses the electric field of the laser pulse, can be used to control electronic branching ratios in non-adiabatic photodissociation without any absorption of light [1]. We illustrate the use of this tool in creating molecular frame alignment, via our technique of `switched’ wavepackets. We demonstrate full 3D, field-free, axis alignment of an asymmetric top rotor [2] – literally ‘fixing the molecule in space’ in order to make a measurement.

of unpaired atoms. Control of such interactions may have applications in quantum computation in an optical lattice. Transport of the atoms to overlapping wells is achieved through a microwave drive between hyperfine levels in a polarization-gradient.

BRIAN MISCHUCK, IVAN DEUTSCH, University of New Mexico — We describe a scheme to probe the spectrum of interacting Cs atoms

Experimental results, in agreement with simulations, demonstrate that square pulses are preferable to both single-step and gaussian pulses. We also study the

decay of coherence. Here we present studies optimizing echo pulses and using the resulting echoes to study the properties of the sources of decoherence. To generate echo pulses, we use a combination of lattice displacements and delays in order to couple the vibrational states. Our calculations using the time-dependent close-coupling method are found to be in excellent agreement with recent measurements and other non-perturbative calculations.

9:12AM N3.00003 Differential cross sections for the photoionization of two-electron systems. JAMES COLGAN, Los Alamos National Laboratory — The time-dependent close-coupling approach has recently been used to compute fully differential cross sections for various electron- and photon-impact ionization processes of light atoms and molecules, including the double photoionization of He and Be and the electron-impact ionization of H and He. This talk will give a review of these recent developments and present our latest calculations, including the triple differential cross sections arising from the double photoionization of the H2 molecule. Our calculations using the time-dependent close-coupling method are found to be in excellent agreement with recent measurements and other non-perturbative calculations.

9:48AM N3.00004 Fully Differential Studies on Atomic Few Body Problems, ROBERT MOSHAMMER, MPI for Nuclear Physics, Heidelberg — Within the last few years, using many-particle imaging techniques (so called reaction microscopes or COLTRIMS spectrometer), numerous fully differential studies of atomic break-up reactions induced by single photon impact, intense laser pulses in the optical and VUV (FEL pulses) as well as by electron and ion impact have been performed. The results of a few selected examples will be discussed during the talk with special emphasis on single ionization of atoms by fast ion impact, a subject that has been studied extensively over decades but measurements of fully differential cross sections (FDCS) were not possible before the advent of reaction microscopes. Such FDCS data are known to be very sensitive to the collision dynamics and they can be considered as the ultimate test of single ionization theories. Recent results for ionization of He in collisions with various projectiles over a wide range of perturbation strengths Z/\nu (projectile charge to velocity ratio) from Z/\nu = 0.1 up to 4.4 reveal significant discrepancies between theory and experiment. The experimental results are discussed in terms of possible higher order ionization mechanisms which are not taken into account in theory. In addition, the possible influences of experimental uncertainties, not considered in most of the theoretical models, will be discussed.

Friday, June 8, 2007 8:00AM - 10:24AM — Session N3 Fully-Differential Studies of Atomic Few-Body Problems TELUS Convention Centre Macleod B

8:00AM N3.00001 Recent Theoretical Progress for Treating Charged Particle Ionization of Atoms and Molecules, DON MADISON, University of Missouri-Rolla — The field of atomic and molecular ionization by charged particle impact has seen exciting advances over the last few years as a result of the development of the COLTRIMS method. Using COLTRIMS, one can get three-dimensional fully differential cross sections (FDCS) for essentially any projectile and any target. This work complements the results of more conventional spectrometers which means that we are getting a much clearer picture of the ionization process. As a result of the rapid experimental advances, the theoretical models are being more stringently tested. This talk will examine the theoretical advances that have been made in the last few years for light and heavy particle ionization of atoms and molecules.

1Work supported by NSF grant PHY-0456528

8:36AM N3.00002 Interference, Correlation and Entanglement in Molecular Double Ionization, REINHARD DÖRNER, University Frankfurt — Photoionization of a diatomic resembles the situation of a traditional double slit. We present a series of experiments on double ionization of H2, where we find evidence of this diffraction pattern in the angular distribution of the electrons in the molecular fixed frame. This interference is gradually lost as the momentum exchange of the electrons is increased, illustrating the transition from quantum to classical behavior. We show that the quantum intererece is buried in the entangled two body wavefunction and can be unraveled by imaging the full correlated multipartical final state phase space.

9:12AM N3.00003 Differential cross sections for the photoionization of two-electron systems. JAMES COLGAN, Los Alamos National Laboratory — The time-dependent close-coupling approach has recently been used to compute fully differential cross sections for various electron- and photon-impact ionization processes of light atoms and molecules, including the double photoionization of H and Be and the electron-impact ionization of H and He. This talk will give a review of these recent developments and present our latest calculations, including the triple differential cross sections arising from the double photoionization of the H2 molecule. Our calculations using the time-dependent close-coupling method are found to be in excellent agreement with recent measurements and other non-perturbative calculations.

9:48AM N3.00004 Fully Differential Studies on Atomic Few Body Problems, ROBERT MOSHAMMER, MPI for Nuclear Physics, Heidelberg — Within the last few years, using many-particle imaging techniques (so called reaction microscopes or COLTRIMS spectrometer), numerous fully differential studies of atomic break-up reactions induced by single photon impact, intense laser pulses in the optical and VUV (FEL pulses) as well as by electron and ion impact have been performed. The results of a few selected examples will be discussed during the talk with special emphasis on single ionization of atoms by fast ion impact, a subject that has been studied extensively over decades but measurements of fully differential cross sections (FDCS) were not possible before the advent of reaction microscopes. Such FDCS data are known to be very sensitive to the collision dynamics and they can be considered as the ultimate test of single ionization theories. Recent results for ionization of He in collisions with various projectiles over a wide range of perturbation strengths Z/\nu (projectile charge to velocity ratio) from Z/\nu = 0.1 up to 4.4 reveal significant discrepancies between theory and experiment. The experimental results are discussed in terms of possible higher order ionization mechanisms which are not taken into account in theory. In addition, the possible influences of experimental uncertainties, not considered in most of the theoretical models, will be discussed.

Friday, June 8, 2007 8:00AM - 10:24AM — Session N4 Ultracold Atoms in Optical Traps and Optical Lattices TELUS Convention Centre Macleod A1-A2

8:00AM N4.00001 Cooling of individual neutral atoms in an optical lattice, MICHAEL GIBBONS, PEYMAN AHMADI, KÉVIN FORTIER, SOO KIM, MICHAEL CHAPMAN, Georgia Institute of Technology — We study the lifetime of individual neutral rubidium atoms trapped in a one-dimensional optical lattice. By using optical molasses to continuously cool the trapped atoms, we achieve vacuum-limited lifetimes greater than 200 s. Without cooling, we observe negligible atom loss within the first 5 s; thereafter, they are observed to decay with a 15 s lifetime. We use a Fokker-Planck [1] equation to simulate the evolution of the cloud in the optical lattice. By fitting the observed population remaining in the lattice to the theoretical predictions, we infer the initial temperature and heating rate of the cloud. Motivated by these results, we have developed a pulsed cooling scheme that maintains very long lifetimes with a low duty cycle (<1%) of applied cooling.


8:12AM N4.00002 Echo pulses and temporal decay of motional coherence in optical lattices, S. MANESHI, C. ZHUANG, M. PARTLOW, A.M. STEINBERG, CQIQC, IOS and Department of Physics, University of Toronto — We study the quantized centre-of-mass motion of 85Rb atoms trapped in an optical lattice. We have measured the coherence between the quantum vibrational states of the atoms in the lattice wells, and observe a decay of coherence. Here we present studies optimizing echo pulses and using the resulting echoes to study the properties of the sources of decoherence. To generate echo pulses, we use a combination of lattice displacements and delays in order to couple the vibrational states. Experimental results, in agreement with simulations, demonstrate that square pulses are preferable to both single-step and gaussian pulses. We also study the coupling efficiency as a function of lattice depth, finding that this process is more efficient in shallow lattices. We will discuss a number of other avenues for further improving state coupling, including coherent control via interfering pathways, and adiabatic passage. We study the decay of echo amplitude over time in both 1D and 3D lattices. In both cases, we observe an initial exponential decay of echo amplitude followed by a plateau before a final decay. We will discuss the relationship of these features to the time-correlation function of the well-depth fluctuations experienced by the atoms.

8:24AM N4.00003 Probing Molecular Interactions of Cs in an Optical Lattice for Quantum Information, BRIAN MISCHUCK, IVAN DEUTSCH, University of New Mexico — We describe a scheme to probe the spectrum of interacting Cs atoms in an optical lattice. Transport of the atoms to overlapping wells is achieved through a microwave drive between hyperfine levels in a polarization-gradient lattice. The spectral response of pairs of atoms to microwaves can be used to measure the effect of the interactions, even in the presence of a large background of unpaired atoms. Control of such interactions may have applications in quantum computation.
Finally, we demonstrate confinement of cold Rb atoms in these traps using light that is blue-detuned by ∼ 5 nm from the D2 line. SLM is used to control and optimize the propagation and trapping characteristics of these toroidal beams, which we analyze both numerically and experimentally. Variation \( n_\phi \) created by modifying the phase of a Gaussian laser beam with a spatial light modulator (SLM). By combining a radial phase discontinuity with an azimuthal phase variation, we create single-beam, blue-detuned, toroidal optical traps for cold atoms. These are significant attention for both fundamental and applied research. We demonstrate single-beam, blue-detuned, toroidal optical traps for cold atoms. These are

**9:00AM N4.00006 Species-selective optical lattices, L.J. LEBLANC, J.H. THYWISSEN, Department of Physics, University of Toronto, 60 St. George Street, Toronto ON M5S 1A7, Canada — In binary mixtures of ultracold alkali atoms, we consider possibilities for creating an optical lattice seen by one atomic species (the “target”) but not the other (the “spectator”) [1]. Two schemes for single-frequency trapping are explored and compared in terms of their trap depths and heating rates. A “tune-in” scheme, where the trapping frequency is nearly resonant with the target and far detuned from the spectator, is found to be preferable for fermion-boson mixtures of Li-Na Li-K and K-Na. A “tune-out” scheme, where the trapping frequency is chosen between the D1 and D2 lines of the spectator element, is favored for Li-Cs, K-Rb, Rb-Cs, K-Cs and Li-Cs. These schemes lend themselves to a number of applications, including the creation of a lattice for the target species in the presence of a phonon-like background, the tuning of relative effective mass of the species, and the isothermal increase of phase space density in the target species. Interactions pose an upper bound on the selectivity of the lattice, since the periodically modulated density of the target can create a periodic interaction potential on the spectator. Ref: [1] L.J. LeBlanc and J.H. Thywissen, arXiv:cond-mat/0702034.

**9:12AM N4.00007 Heteronuclear molecules in a 3D optical lattice, C. OSPELKAUS, S. OSPELKAUS, L. HUMBERT, P. ERNST, K. SENGSTOCK, K. BONGS, Institut fuer Physik, Universitaet Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany, F. WERNER, Laboratoire Kastler Brossel, Ecole Normal Superieure, 24 rue Lhomond, 75231 Paris Cedex 05, France, F. DEURETZBACHER, K. Plassmeier, D. Pfannkuche, I. Inst. fuer Theoretische Physik, Universitaet Hamburg, Jungiusstrasse 9, 20355 Hamburg, Germany — We report on experiments with Fermi-Bose mixtures confined in 3D optical lattices, especially the first production of ultracold long-lived heteronuclear molecules in a 3D optical lattice. The molecules are associated from a quantum degenerate mixture of fermionic \(^{40}\text{K}\) and bosonic \(^{87}\text{Rb}\) atoms loaded into a 3D optical lattice. Molecules are produced at a heteronuclear Feshbach resonance in the vicinity of 546.7(1) G. Molecule formation is studied on both the attractive and the repulsive side of the resonance. The binding energy of the heteronuclear molecules is precisely determined by rf spectroscopy and compared to a theoretical model based on a pseudopotential approach. We also characterize both the lifetime of the sample and the efficiency of rf association; comparison to the pseudopotential model results in excellent agreement.

**9:24AM N4.00008 Atomtronics: Realizing the behavior of electronic components in ultracold atomic systems\(^{1}\), RON PEPINO, JILA and University of Colorado, J. COOPER COLLABORATION, B.T. SEAMAN COLLABORATION, D. ANDERSON COLLABORATION, M.J. HOLLAND COLLABORATION\(^{2}\) — Atomtronics focuses on creating an analog of electronic devices and circuits with ultracold atoms. Such an analog can come from the highly tunable band structure of ultracold neutral atoms trapped in optical lattices. Solely by tuning the parameters of the optical lattice, we demonstrate that conditions can be created that can provide an analog function as well. We present our model and show how the atomtronic diode, field effect transistor, and bipolar junction transistor can all be realized. Our analog of these fundamental components exhibit precisely-controlled atomic signal amplification, trimming, and switching (on/off) characteristics. In addition, the evolution of dynamics of the artificial atomic circuits within these systems is completely reversible. This implies a possible use of atomtronics systems in the development of quantum computational devices.

**9:36AM N4.00009 Optical dipole trapping of short-lived radioactive \(^{82}\text{Rb}\), DAVID FELDBAUM, HAIYAN WANG, Los Alamos National Lab, JONATHAN WEINSTEIN, University of Nevada - Reno, DAVID VIEIRA, XINXIN ZHAO, Los Alamos National Lab, LOS ALAMOS NUCLEAR CHEMISTRY ATOM TRAPPING TEAM — The application of the techniques of laser cooling and trapping of radioactive atoms holds a great promise for fundamental measurements. To date only a few radioactive isotopes have been trapped in MOTs and/or in magnetic traps. All-optical trapping of radioactive atoms has not, until now, been demonstrated. Optical dipole trapping may be the most desirable method, as it introduces less systematic problems in certain cases. We have experimentally demonstrated the trapping of short-lived \(^{85}\text{Rb}\) in an optical lattice, and we plan to study the optical pumping of these atoms into a stretched state for polarization studies. Our latest results will be presented.

**9:48AM N4.00010 Single-beam, dark toroidal optical traps for cold atoms, SPENCER OLSON, MATTHEW TERRACIANO, MARK BASHKANSKY, ZACHARY DUTTON, FREDRIK FATEMI, Naval Research Laboratory — Toroidal atom confinement has received significant attention for both fundamental and applied research. We demonstrate single-beam, blue-detuned, toroidal optical traps for cold atoms. These are created by modifying the phase of a Gaussian laser beam with a spatial light modulator (SLM). By combining a radial phase discontinuity with an azimuthal phase variation \( n_\phi \), where \( n_\phi \) is an integer, we produce a beam forming a ring-shaped intensity null surrounded harmonically in all directions by high intensity. The SLM is used to control and optimize the propagation and trapping characteristics of these toroidal beams, which we analyze both numerically and experimentally. Finally, we demonstrate confinement of cold Rb atoms in these traps using light that is blue-detuned by ∼ 5 nm from the D2 line.
Quantum Coherence in a Disordered Bose-Einstein Condensate

YONG P. CHEN, J. HITCHCOCK, D. DRIES, M. JUNKER, C. WELFORD, R.G. HULET, Department of Physics and Astronomy and Rice Quantum Institute, Rice University, Houston TX 77005 — Quantum coherence underlies such phenomena as superfluids and superconductors. We have performed an experiment on a Bose-Einstein condensate (BEC) subjected to a disordered potential, and found evidence that finite quantum coherence may still exist in an insulating state. We create a large BEC of $^7$Li atoms in their (1,1) state in an elongated optical dipole trap. We then project laser speckle onto the atoms to make a disordered potential, where the disorder strength ($V_d$) is tunable by varying the laser intensity. As $V_d$ is increased, we observe a suppression of the center of mass transport ($d$, $V_d$) is increased, we observe a suppression of the center of mass transport. When the gate width was made narrower than one optical cycle, the supercontinuum can be interpreted as a result of emission of a single electron and ion re-collision. When the polarization gate width was wider, only the XUV shift showed up with respect to the change in the CE phase in absence of filamentation. When the polarization gate width was wider, only the XUV shift showed up with respect to the change in the CE phase.

Supersolid $^4$He at Low Temperature

HUAI-BIN ZHUANG, XI DAI, MICHAEL MA, FU-CHUN ZHANG, The University of Hong Kong — The observation of NCRI in solid $^4$He reported by Kim and Chan reignited interests in the existence of supersolid in nature. Though plenty of theories assume that the mechanism of the supersolid is BEC of point defects, namely vacancies and interstitials, some theories and experiments show that this can be extended to molecular media. In this work, the mechanism of the effects of CE phase on the polarization (XUV) supercontinuum in the spectrum domain. Previous numerical simulations and experiments show that the attosecond pulses and the corresponding XUV spectra can be used to monitor such attosecond evolution in dissociating systems such as $H_3^{+2}$ to $H_+^+$ and $H_2^+$ [2]. We examine by detailed solutions of the time-dependent Schrödinger equation, TDSE, the HHG spectrum for the dissociating linear $H_3^{++}$ system subjected to an intense few cycle laser pulse at different wave lengths and internuclear distances where an adiabatic avoided crossing occurs between selected electronic states. Criteria for possibly extracting electron-nuclear nonadiabatic couplings from HHG will be presented.

1 Supported by NSF, ONR, the Welch and the Keck Foundations.

Supersolid $^4$He at Low Temperature

Session N5 Attosecond and Femtosecond Dynamics TELUS Convention Centre Macleod A3-A4

8:00AM N5.00001 Harmonic Generation at Nonadiabatic Crossings of Electronic States, ANDRE D. BANDRAUK1, SAMIRA BARKAMI, Universite de Sherbrooke, ATTITUDE SCIENCE TEAM — Nonadiabatic crossings of molecular electronic states create coherent superpositions of electronic wave functions. The time evolution of such coherent electronic states on “attosecond” time scale depends on the energy separation of these states as a function of internuclear distance [1]. High order harmonic generation, HHG, induced by ultrashort intense laser pulses can be used to monitor such attosecond evolution in dissociating systems such as $H_3^{++}$ to $H_+^+$ and $H_2^+$ [2]. We examine by detailed solutions of the time-dependent Schrödinger equation, TDSE, the HHG spectrum for the dissociating linear $H_3^{++}$ system subjected to an intense few cycle laser pulse at different wave lengths and internuclear distances where an adiabatic avoided crossing occurs between selected electronic states. Criteria for possibly extracting electron-nuclear nonadiabatic couplings from HHG will be presented.

1 Canada Research Chair

8:12AM N5.00002 Propagation Effects on Attosecond Pulse Generation in Molecular Media, ANDRE D. BANDRAUK2, Universite de Sherbrooke, EMMANUEL LORIN, Centre de recherches mathematiques Montreal, MATHematiques APPliquEES TEAM — We investigate numerically on large scale parallel supercomputer the dynamics of “attosecond” pulse generation created from high order harmonic generation, HHG, in molecular media. Propagation of an intense 5-fs Ti:S (800 nm) in a $H_2^+$ gas medium is studied from numerical solution of the coupled time-dependent Schrödinger (TDSE) and Maxwell equations. Exact 1-D and 3-D solutions of the $H_2^+$ TDSE are compared as the 1-D molecular model coupled to 3-D Maxwell equations allows for including up to 10 000 molecules on an appropriate grid. The simulations allow for exact calculation of electron ionization and recombination leading to HHG with propagation effects. In particular we have designed mathematical boundary conditions which allow free ionized electrons to be transmitted from one molecule to another. Instabilities such as filamentation of the incident intense (800 nm) pulse are observed as a function of medium density. The effect of 3- photon resonances which occur in atmospheric filamentation are examined using the present novel algorithm.

1 Canada Research Chair

8:24AM N5.00003 Effect of Carrier Envelope Phase On Attosecond Two-Slit Interference, MAHENDRA M SHAKYA, S. GILBERTSON, C. LI, E. MOON, C.M. NAKAMURA, J. TACKETT, H. MASHIKO, Z. CHANG — High order harmonics generated by polarization gating have been experimentally demonstrated to be sensitive to the carrier envelope phase. Supercontinuum extreme ultraviolet spectra generated by the polarization gating method were mapped for several minutes while changing the thickness of a fused silica plate on the beam path while the CE phase the amplifier and the oscillator were locked. A shift in the XUV spectra associated with appearance of supercontinuum at pi radian spacing was observed when the gate width was made narrower than one optical cycle. The supercontinuum can be interpreted as a result of emission of a single electron and ion re-collision. When the polarization gate width was wider, only the XUV shift showed up with respect to the change in the CE phase.

8:36AM N5.00004 Simulation of carrier-envelope phase effects on polarization gated attosecond spectra, ZENGHANG CHANG, Kansas State University — Polarization gating of harmonic generation by a laser field with a time dependent ellipticity has been demonstrated as a powerful method to produce single attosecond pulses. A single attosecond in time domain correspond to an extreme ultraviolet (XUV) supercontinuum in the spectrum domain. Previous numerical simulations and experiments show that the attosecond pulses and the corresponding spectra are sensitive to the variation of the carrier-envelope (CE) phase of the laser pulses. In this work, the mechanism of the effects of CE phase on the polarization gating process is investigated. In the simulation, the laser pulses for polarization gating are obtained by transforming linearly polarized few-cycle pulses with a quartz plate and an achromatic waveplate. The laser pulse can be decomposed into two orthogonally polarized pulses, i.e., a driving pulses and a gating pulse. The CE phase is defined as the phase of the driving field at the time when the ellipticity of combined pulses is zero. We found that when the CE phase changes from zero to Pi, the XUV spectra evolves from a supercontinuum to discrete harmonic peaks and then back to a supercontinuum. The evolution can be understood by the interference of the two attosecond pulses. The amplitudes and spectral phases of two pulses are controlled by the CE phase and the envelope of the driving field.
The sweeping method was confirmed by the XUV spectrum generated by polarization gating. The correlation between the relative CE phase and the high harmonic peak energy showed a $\pi$ range.

The CE phase stability was monitored by out-loop feedback controlling the effective distance between two gratings in the stretcher and compressor on the CE phase variation. By feedback controlling the effective distance between two gratings in the stretcher, the relative CE phase of the amplified pulses was stabilized with a 180 mrad rms error. Furthermore, by smoothly changing the locking reference, the grating separation in the stretcher and compressor on the CE phase variation.

The sweeping method was confirmed by the XUV spectrum generated by polarization gating. The correlation between the relative CE phase and the high harmonic peak energy showed a $\pi$ range.
10:12AM N5.00012 The Laser-Assisted Photoemission from Surfaces

Luis MIAJA AVILA, Guido SAATHOFF, Margaret MURNANE, Henry KAPTEYN, JILA, Univ. of Colorado, Martin AESCHLIMANN, Univ. of Kaiserslautern, Germany — The Laser-assisted photoelectric effect (LAPE) is a powerful tool for characterizing femtosecond-to-attosecond EUV pulses, and for time-resolved spectroscopy of electron dynamics in atoms. Recently, we observed this process for the first time in the original manifestation of the photoelectric effect i.e. photoemission from surfaces. Irradiating a surface in infrared light as an EUV photon ejects an electron from a surface, this electron can also absorb or give-up energy from the infrared field. We can extract sideband amplitudes from the continuous photoemission spectra, making it possible to record a cross-correlation between the two beams. This result is of interest because LAPE has the potential to study ultrafast, femtosecond-to-attosecond time-scale electron dynamics in solids and in surface-adsorbate systems where complex, correlated, electron relaxation processes are expected. However to extend these applications of LAPE to surfaces, it must be unambiguously distinguished from hot electron excitation, above-threshold photoemission, and space charge acceleration, as these effects can potentially lead to similar modifications of the photoemission spectrum. We present new data that reveals surface LAPE in a regime where a wealth of surface-adsorbate dynamics is known to occur.

Friday, June 8, 2007 8:00AM - 10:24AM — Session N6 Electron Impact Ionization, Recombination, and Attachment	TELUS Convention Centre

8:00AM N6.00001 Dissociative recombination of H3+1

Samantha Santos, Viatcheslav Kokouline, Department of Physics of University of Central Florida, Chris Greene, Department of Physics and JILA, University of Colorado — The process of dissociative recombination (DR) of the H3+ ion has been studied over the past years and it was found that the coupling of vibrational and electronic degrees of freedom plays a crucial role in the mechanism; when the Jahn-Teller coupling effect was incorporated into the theoretical treatment it yielded DR rates in much better agreement with experiments. The previous work on H3+ was performed using hyperspherical coordinates and Siegert states for the vibrational wave functions. SVD technique employed in this study provides more accurate vibrational energies than the Siegert state approach for it takes into account the nonadiabatic coupling between different adiabatic channels. Another improvement towards theory-experiment agreement was to take into account the conditions and parameters of the experiments performed. The present approach uses SVD vibrational states in the calculation of H3+ DR rates and accounts for experimental conditions. Incorporating averaging procedures that describe better the experimental conditions improves the agreement between theory and experiment. Results for vibrationally-excited initial states of H3+ are also presented in this work.

This work has been supported by the National Science Foundation under Grant No. PHY-0427460 and Grant No. 0427376, by allocation of NERSC supercomputing resources.

8:12AM N6.00002 Formation of H3+ in methanol: an intramolecular bond rearrangement study

San kar De, Jyoti Rajput, A. Roy, C. P. Safvan, Inter-University Accelerator Centre, New Delhi - 110067, India, P. N. Ghosh, Dept. of Physics, University of Calcutta, Kolkata - 700009, India — We report here results of TOF multi-hit coincidence experiment [1] that provide evidence for intramolecular reactions involving proton coagulation in methanol [2] after interaction with 1.2 MeV Ar++ projectiles produced from the ECR ion source in the LEIBF laboratory of Inter-University Accelerator Centre, India. Quite remarkably, we have observed the formation of H3+ due to movement of protons within the multiply charged parent molecular ion through two-body process (CH3OH+ → H3+ + COH)+ and such bond formation occurs before the Coulomb repulsion makes the fragment ions to fly apart. Analysis of the fragmentation pattern of CH3OH+ has been carried out using ab initio quantum chemical techniques. Structural calculations indicate that the formation of H3+ is the preferred pathway in the overall fragmentation dynamics of the ground state of this alcohol. The field generated from highly charged ions induces the system to rearrange its structure following a minimum energy pathway and form hydrogen molecular ions. Repeating the experiment with CH3OD confirm our bond rearrangement phenomenon and establish that H3+ formation occurs only within the methyl group of the alcohol. Ref: [1] S. De et al. NIMB, 243, 435 (2006) [2] Sankar De et al. PRL, 97, 213201 (2006)

8:24AM N6.00003 Yields of electronically excited product states in the dissociative recombination of N2H+, HCO+, HOCl+, and NHC+1

Rainer Johnsen, University of Pittsburgh, Richard Rosati, Smithsonian Astrophysical Observatory, Massachusetts, Daphne Pappas, Army Research Laboratory, Mirek Skrzypkowski, Prometheus Energy Company, Michael Golde, University of Pittsburgh — We have determined branching fractions of radiating products of the dissociative electron-ion recombination (DR) of the astrophysically important ions N2H+, HCO+, HOCl+, and NHC+, using the flowing-afterglow technique and absolute spectroscopy. State-specific yields were derived by fitting spatially resolved emission band intensities to model calculations. We find that DR of N2H+ results in N2(3Πg, v ≥ 1), with a yield of (19±8)%. DR of HCO+ forms the long-lived CO(a1Π) state with a yield of (23 ± 12)%, but DR of its isomeric form, HOCl+, favors formation of the triplet states CO(v = 3Σ+2) and CO(d = 3Δ) with a combined yield of greater than 40%. The yield of CN(B) from DR of NHC+ was found to be (22±8)%, while that of CN(A) is (14±5)%. The vibrational distributions of the product electronic states do not follow a simple pattern. In some cases, the distributions are close to those predicted by Bates’ impulse model but we also find partially inverted distributions, and some that extend to very high vibrational quantum numbers.

8:36AM N6.00004 Complete theoretical treatment of Dissociative Recombination of LiH+ and LiH2+

Daniel Haxton, University of Colorado, Boulder and JILA, Roman Curik, University of Colorado, Boulder and JILA; and the J. Heyrovsky Institute of Physical Chemistry, Prague, Czech Republic, Chris Greene, University of Colorado, Boulder and JILA — Studies of LiH+ and LiH2+ ions are motivated by their role in the chemistry of the early universe. They are diatomic and triatomic prototypes of the indirect dissociative recombination (DR) process, in which a colliding electron destroys the molecule through Rydberg capture pathways. We apply ab-initio multi-channel quantum defect theory in combination with ro-vibrational frame transformation techniques to calculate DR for these fundamental ions. Alternate versions of the vibrational frame transformation employing either Siegert states or Exterior Complex Scaling are employed. In both cases every rovibrational degree of freedom is included in the calculations, without approximation to the nuclear kinetic energy operator. In case of the LiH+ ion we identify the underlying mechanism behind the suprisingly high DR rate recently measured in storage-ring experiments. Calculated DR rate coefficients are in a good agreement with the experimental data. This work is supported in part by the NSF.

8:48AM N6.00005 Magnetic field enhancement of dielectronic recombination

Edward Shuman, Wei Yang, Tom Gallagher, University of Virginia — We report the results of the effects of combined electric and magnetic fields on dielectronic recombination (DR) from a continuum of finite bandwidth. Specifically, we have examined the process Ba 6p1/2Sg → Ba 6p1/2Sn → Ba 6s1/2Sn + hν in the presence of electric fields from 0-7 V/cm and magnetic fields from 0-250 G. Our observations elucidate the requirements for magnetic field enhancement of the DR rate. In particular, they demonstrate that the magnetic coupling must only be comparable to the electric field splitting of the intermediate autoionizing Rydberg states, but also to their decay rates.

This work has been supported by the U.S. Department of Energy.
9:00AM N6.00006 Optical Excitation Functions of $N_2^+$, AMANDA FRICKE, TIMOTHY GAY, University of Nebraska — Using a new apparatus designed to minimize systematic sources of error, we have measured the electron-impact optical excitation functions for the $B^2\Sigma_g^+ - X^2\Sigma_g^+$ 391.4nm transition in $N_2^+$. Incident-electron energies ranged from 20-500 eV. By taking data at pressures less than 0.5 mTorr the possible effects of radiation trapping are significantly reduced. We compare our results with previously published data for this transition and find good agreement with them [1]. We discuss steps we have taken to ensure accurate normalization of photon count rates to both pressure and beam current, and discuss potential error in our results due to radiation trapping. [1] B.N. Srivastava and I.M. Mirza. Phys. Rev. 176, 137 (1968).

9:12AM N6.00007 Single and Double Ionization of Helium by Charged Ions, M. FOSTER, J. COLGAN, Los Alamos National Laboratory, Theoretical Division, M.S. PINDZOLA, F. ROBICHEAUX, Auburn University — We present total cross sections for single and double ionization of helium by various charged ion impact. A non-perturbative time-dependent close-coupling method (TDCC) has been developed to treat the correlated dynamics of ionized electrons by bare-ion impact [Journal of Physics B (accepted)]. The two-electron helium wavefunction is subject to a time-dependent projectile interaction. The projectile-atom interaction is constructed as a multipole expansion that includes monopole, dipole, quadrupole, and octopole terms. For proton, antiproton, and alpha particle impact, good agreement is obtained between our calculations and experimental measurements of total single and double ionization cross sections. We will also report on our progress in using the TDCC method to extract differential cross sections for double ionization by fast protons [Physical Review Letters 90, 243201 (2003)].

9:24AM N6.00008 Dissociative Electron Attachment to Acetylene, S.T. CHOIRON, A.E. OREL, Department of Applied Science, University of California, Davis — Experimental studies of electron impact on acetylene show the presence of a $\pi^*$-shape resonance at 2.6 eV which leads to dissociation into C$_2$H$^-$ and H. In their ground state, these fragments have $^1\Sigma$ and $^1\Sigma$ symmetries respectively; therefore, the DEA process involves a break of the linear symmetry of acetylene and predissociation of the $^3\Pi_g$ resonance in bent geometries. We performed electron scattering calculations using the complex Kohn variational method to determine the resonance parameters of this system. We discuss the dynamics of dissociation into the product channels and report the computed DEA cross sections. The results are then compared to available experimental findings. Work supported by NSF PHY-05-55401.

9:36AM N6.00009 Dissociative Electron Attachment to chloroacetylene, V. NGASSAM, A.E. OREL, Department of Applied Science, University of California Davis — The production of two fragments with $\Sigma$ symmetry from electron-impact dissociation of C$_2$HCl$_2$, which has only a low lying $\pi^*$ resonance at equilibrium geometry, has been explained by the existence of interactions with $\sigma^*$ resonances at bent geometries. We are investigating the presence of such multidimensional effects in the dissociative attachment of chloroacetylene (C$_2$HCl). We have performed electron scattering calculations using the Complex Kohn variational method to determine the resonance energies and widths of the chloroacetylene resonances as a function of both the Cl-C$_2$H bond distance as well as the variation with C-C stretch and bend. We will discuss our results and our prediction of the dissociation dynamics in comparison to the findings for C$_2$H$_2$. This work was supported by the U.S. DOE Office of Basic Energy Sciences, Division of Chemical Sciences and the National Science Foundation, PHY-05-55401.

9:48AM N6.00010 A universal model for electron impact ionization of K, L and M-shells, FAZLEY BARY MALIK, Southern Illinois University Carbondale, A.K.F. HAQUE, M.A. UDDIN, A.K. BASAK, Rajshahi University, B.C. SAHA, Florida A&M University, K.R. KARIM, Illinois State University — A modified version of the original Kolbenstvedt model, which has its roots in quantum electrodynamical description of electron-electron scattering, will be presented. This modified model describes reasonably well cross sections of K-shell ionization of H, He, Li, C, N, O, Mg, Si, P and S, L-shell ionization of Ag, Sn, Ba, Ho, Ta, Au, Pb, Bi and U, and M-shell ionization of Pb, Bi and U, from threshold to a few GeV incident energy. The same model with slight modification to account for the ionic charge is also applicable to ionic targets such as Ne$^8^+$, Mo$^{41^+}$, U$^{92^+}$ from threshold to a few MeV incident energy. Experimentally observed increase of the cross section at high energies seems to be a consequence of the Møller interaction between two interacting electrons.

10:00AM N6.00011 Electron impact ionization of magnesium, DANIEL WEFLEN, XIAOXU GUAN, KLAUS BARTSCHAT, Drake University — We have applied a hybrid method, combining a second-order distorted-wave method for a fast ionizing projectile with an $R$-matrix (close-coupling) approach for the initial bound state and the ejected electron [1], to calculate electron impact ionization of magnesium. Our results will be compared with recent experimental data [2] and predictions from other theoretical approaches [3]. For various kinematical situations, in-plane and out-of-plane, we analyze the sensitivity of the theoretical results to the details of the computational model. We will suggest additional benchmark experiments to test the various theoretical approaches.

1This work is supported by the United States National Science Foundation under grant PHY-0244470.

10:12AM N6.00012 The Role of the Projectile in Simultaneous Excitation-Ionization, A.L. HARRIS, University of Missouri-Rolla, M. FOSTER, Los Alamos National Laboratory, J.L. PEACHER, D.H. MADISON, University of Missouri-Rolla — The importance of projectile interactions in fully differential cross sections (FDCS) is explored for the problem of simultaneous excitation-ionization by electron impact. We will compare the results of two theories- the first Born approximation-Hartree Fock (FBA-HF) and the four-body distorted wave model (4DW). In the first Born approximation-Hartree Fock (FBA-HF), the projectile electron is treated as a plane wave, the ejected electron is treated as a Hartree Fock distorted wave, and the final state Coulomb interaction between the two continuum electrons is ignored. In the 4DW model, all continuum electrons are treated as Hartree Fock distorted waves, and a Coulomb distortion factor is included in the final state to account for the interaction between the two outgoing electrons. Results are presented for an incident electron energy of 500 eV and will be compared to experimental data.

Friday, June 8, 2007 10:30AM - 12:54PM – Session P1 2-Dimensional Physics TELUS Convention Centre Macleod D
10:30AM P1.00001 Bose gas in Flatland. ZORAN HADZIBABIC, Laboratoire Kastler Brossel, Ecole Normale Superieure, Paris — Physics of a Bose gas in two dimensions (2D) is quite different from the usual 3D situation. In a homogeneous 2D fluid of identical bosons long-range order is always destroyed by long wavelength thermal fluctuations, but the system can nevertheless become superfluid at a finite critical temperature. This phase transition does not involve any symmetry breaking and in the Berezinskii-Kosterlitz-Thouless (BKT) paradigm it is explained in terms of binding and unbinding of pairs of vortices with opposite circulations. Above the critical temperature, proliferation of unbound vortices is expected. Using optical lattice potentials we can create two parallel, independent 2D atomic clouds with similar temperatures and chemical potentials. When the clouds are suddenly released from the trapping potential and allowed to freely expand, they overlap and interfere. This realizes a matter wave heterodyning experiment which gives direct access to several features of the phase distributions in the two planes. Long wavelength phase fluctuations create a smooth and random variation of the interference fringes and free vortices appear as sharp dislocations in the interference pattern. Temperature study of these effects supports the BKT picture of the development of quasi-long-range coherence in these systems.


11:06AM P2.00002 Rydberg excitation of cold atoms: dipole blockade and ionization. PIERRE PILLET, Laboratoire Aimé Cotton, CNRS, Bât.505, Univ Paris-Sud, 91405 Orsay, France — Cold Rydberg atoms are fascinating because they are at the frontier of atomic, solid state and plasma physics. Spectacular effects have their origin in the long-range dipole-dipole interactions between cold Rydberg atoms. In the presence of an electric field or at a Förster resonance, the Rydberg excitation can be limited. Electric-field induced dipole blockade allows us to limit the excitation of p levels (principal quantum number n=80) up to 80 % in a volume of typical dimension of 0.1 mm. The Förster resonance configuration, for which Rydberg atoms exchange resonantly internal energy, is observed for n below 42 and leads to 30 % efficiency in dipole blockade [T. Vogt et al., Phys. Rev. Lett. 97, 083003 (2006)]. Both experiments have permitted us to analyze the role of saturation and the role of the presence of one or a few spurious ions. The application of the dipole blockade effect in the realization of scalable quantum gates will be discussed. In a dense ensemble, cold Penning collisions between Rydberg atoms can be at the origin of an ionic space charge, important enough to then trap the electrons leading to the evolution towards an ultracold plasma formed in a ionization avalanche process. We demonstrate the possibility to control the mutual dipolar force between Rydberg atoms.

11:06AM P2.00002 Rydberg excitation of cold atoms: dipole blockade and ionization. PIERRE PILLET, Laboratoire Aimé Cotton, CNRS, Bât.505, Univ Paris-Sud, 91405 Orsay, France — Cold Rydberg atoms are fascinating because they are at the frontier of atomic, solid state and plasma physics. Spectacular effects have their origin in the long-range dipole-dipole interactions between cold Rydberg atoms. In the presence of an electric field or at a Förster resonance, the Rydberg excitation can be limited. Electric-field induced dipole blockade allows us to limit the excitation of p levels (principal quantum number n=80) up to 80 % in a volume of typical dimension of 0.1 mm. The Förster resonance configuration, for which Rydberg atoms exchange resonantly internal energy, is observed for n below 42 and leads to 30 % efficiency in dipole blockade [T. Vogt et al., Phys. Rev. Lett. 97, 083003 (2006)]. Both experiments have permitted us to analyze the role of saturation and the role of the presence of one or a few spurious ions. The application of the dipole blockade effect in the realization of scalable quantum gates will be discussed. In a dense ensemble, cold Penning collisions between Rydberg atoms can be at the origin of an ionic space charge, important enough to then trap the electrons leading to the evolution towards an ultracold plasma formed in a ionization avalanche process. We demonstrate the possibility to control the mutual dipolar force between Rydberg atoms.

11:06AM P2.00002 Rydberg excitation of cold atoms: dipole blockade and ionization. PIERRE PILLET, Laboratoire Aimé Cotton, CNRS, Bât.505, Univ Paris-Sud, 91405 Orsay, France — Cold Rydberg atoms are fascinating because they are at the frontier of atomic, solid state and plasma physics. Spectacular effects have their origin in the long-range dipole-dipole interactions between cold Rydberg atoms. In the presence of an electric field or at a Förster resonance, the Rydberg excitation can be limited. Electric-field induced dipole blockade allows us to limit the excitation of p levels (principal quantum number n=80) up to 80 % in a volume of typical dimension of 0.1 mm. The Förster resonance configuration, for which Rydberg atoms exchange resonantly internal energy, is observed for n below 42 and leads to 30 % efficiency in dipole blockade [T. Vogt et al., Phys. Rev. Lett. 97, 083003 (2006)]. Both experiments have permitted us to analyze the role of saturation and the role of the presence of one or a few spurious ions. The application of the dipole blockade effect in the realization of scalable quantum gates will be discussed. In a dense ensemble, cold Penning collisions between Rydberg atoms can be at the origin of an ionic space charge, important enough to then trap the electrons leading to the evolution towards an ultracold plasma formed in a ionization avalanche process. We demonstrate the possibility to control the mutual dipolar force between Rydberg atoms.
11:42AM P2.00003 Rydberg atoms in Antihydrogen Experiments1, FRANCIS ROBICHEAUX, Auburn University
— Recent experiments have observed the formation of antihydrogen atoms by mixing antiprotons and positrons. In most experimental configurations, the antihydrogen is formed through three body recombination while an antiproton traverses a cold positron plasma. These experiments take place with an unusual set of parameters. In particular, the atoms are formed in strong magnetic fields and the positron plasma is much colder than usual plasmas. The anti-atoms that have formed have some unexpected properties. In this talk, I will present the results simulations and measurements that give insight into the kinds of atoms that are formed. The focus will be on properties that might affect the chances of trapping these exotic atoms.

1Support from DOE

12:18PM P2.00004 Forging, trapping, and cooling neutral antimatter: strongly magnetized highly excited antihydrogen atoms1, HOSSEIN SADEGHPOUR, Harvard-Smithsonian Center for Astrophysics — A theoretical framework for the formation of Rydberg atoms in strongly magnetized nonneutral plasma is described with an eye toward the production of highly excited Rydberg antihydrogen atoms at CERN. A number of challenges hindering a quantitative understanding of how H-bar atoms are formed— the details of velocity and field ionization spectra— are overcome. It is shown that a cooling technique due to spontaneous decay efficiently brings the Rydberg atoms to their ground state. The long-time dynamics in strong inhomogeneous magnetic field traps is numerically investigated using classical techniques, whereas the atomic state-specific structure is fully described quantum mechanically. Analytical expressions for the two limits of cooling: adiabatic and sudden cascades— as a function of trapping magnetic multipole order will be given.

Friday, June 8, 2007 10:30AM - 12:54PM – Session P3 The State of the Art in Quantum Cryptography TELUS Convention Centre Macleod B

10:30AM P3.00001 Entanglement-Based Free Space Quantum Key Distribution1, GREGOR WEIHS, Institute for Quantum Computing, University of Waterloo, 200 University Ave W, Waterloo, Ontario, N2L 3G1, Canada — Free-space optical communication can complement fiber optics, when the latter are not readily available or when transmitting to or from a satellite is the goal. I will report on our free-space quantum key distribution experiment that links a source to receivers in two different buildings with a distance of about 1.8 km. There is no direct line of sight between the endpoints. Our implementation is a complete quantum key distribution system that includes error correction and privacy amplification. It is based on the distribution of polarization-entangled photon pairs via optical telescopes from the source location on the roof of a campus building to the building of the Institute for Quantum Computing and the Perimeter Institute for Theoretical Physics respectively. In the future, we want to achieve daylight operation capability and use brighter sources of entangled photon pairs to increase the achievable key rates.

1Partial Funding by NSERC, CIAR, ORDCF, and QuantumWorks

10:06AM P3.00002 Free-space quantum key distribution at GHz transmission rates, JOSHUA BIENFANG, NIST — Quantum key distribution (QKD) can produce unconditionally secure cryptographic key for use in symmetric cryptosystems. We have shown that telecommunications clock-recovery techniques enable the continuous operation of both free-space and fiber QKD systems at transmission rates in the GHz range, limited only by the timing resolution of the single-photon detectors. Taking advantage of improvements in detector timing resolution and FPGA performance that enable transmission rates of 2.5 GHz and higher, we discuss the performance of a free-space QKD system operating in the H$_2$-Fraunhofer window, the classical-channel bandwidth required for post-processing, and the limitations imposed by detector recovery time. We also show that with high-repetition-rate sub-clock gating these higher-resolution detectors can reduce a free-space QKD system’s exposure to solar background photons, thus reducing the quantum-bit error rate (QBER) and improving system performance.

11:42AM P3.00003 Stable operation of a Secure QKD system in the real-world setting1, AKIHISA TOMITA, JST — Quantum Key Distribution (QKD) now steps forward from the proof of principle to the validation of the practical feasibility. Nevertheless, the QKD technology should respond to the challenges from the real-world such as stable operation against the fluctuating environment, and security proof under the practical setting. We report our recent progress on stable operation of a QKD system, and key generation with security assurance. A QKD system should robust to temperature fluctuation in a common office environment. We developed a loop-mirror, a substitution of a Faraday mirror, to allow easy compensation for the temperature dependence of the device. Phase locking technique was also employed to synchronize the system clock to the quantum signals. This technique is indispensable for the transmission system based on the installed fiber cables, which stretch and shrink due to the temperature change. The security proof of QKD, however, has assumed the ideal conditions, such as the use of a genuine single photon source and/or unlimited computational resources. It has been highly desirable to give an assurance of security for practical systems, where the ideal conditions are no longer satisfied. We have constructed a theory to estimate the leakage information on the transmitted key under the practically attainable conditions, and have developed a QKD system equipped with software for secure key distillation. The QKD system generates the final key at the rate of 2000 bps after 20 km fiber transmission. Eavesdropper’s information on the final key is guaranteed to be less than 2$^{-7}$ per bit. This is the first successful generation of the secure key with quantitative assurance of the upper bound of the leakage information. It will put forth the realization of highly secure metropolitan optical communication network against any types of eavesdropping.

1This work was partly supported by NICT.

12:18PM P3.00004 Free-Space Quantum Key Distribution using Polarization Entangled Photons1, CHRISTIAN KURTSIEFER, National University of Singapore — We report on a complete experimental implementation of a quantum key distribution protocol through a free space link using polarization-entangled photon pairs from a compact parametric down-conversion source [1]. Based on a BB84-equivalent protocol, we generated without interruption over 10 hours a secret key free-space optical link distance of 1.5 km with a rate up to 950 bits per second after error correction and privacy amplification. Our system is based on two time stamp units and relies on no specific hardware channel for coincidence identification besides an IP link. For that, initial clock synchronization with an accuracy of better than 2 ns is achieved, based on a conventional NTP protocol and a tiered cross correlation of time tags on both sides. Time tags are used to servo a local clock, allowing a streamed measurement on correctly identified photon pairs. Contrary to the majority of quantum key distribution systems, this approach does not require a trusted large-bandwidth random number generator, but integrates that into the physical key generation process. We discuss our current progress of implementing a key distribution via an atmospheric link during daytime conditions, and possible attack scenarios on a physical timing information side channel to a entanglement-based key distribution system.

1supported by DSTA under POD0309216.
10:30AM P4.00001 Collisional cooling and trapping of molecules, KEVIN E. STRECKER, Sandia National Labs, DAVID W. CHANDLER — Using a crossed molecular beam apparatus, we have shown that under the correct criteria, collisions between supersonic atoms and molecules can yield post-collision molecules at rest in the laboratory frame. This technique was first demonstrated in nitric oxide (NO), and has since been extended to other non-radical diatomics, strong polar molecules, and weak polar molecules. The cooling technique only relies on the momentum of the molecule or atom to be cooled and mass of the collision partner. However, it suffers from the fact that the cold molecules are produced at the crossing of two intense supersonic beams, which leads to glancing and secondary collisions which in turn heat the cold molecules. We have modified the apparatus so that the secondary collisions and heating of the cold molecules is minimized. Our observation time of the cold molecules is limited by the latent velocity distribution of the molecules, which is approximately 50 mK. Under these conditions, we are currently attempting to implement a trap in the collision region to confine the cold molecules.

10:42AM P4.00002 Population transfer in heteronuclear molecules, MICHAELA TSCHERNECK, NICHOLAS BIGELOW, University of Rochester — Heteronuclear molecules are an interesting field of research due to their large electric dipole moment, which can be used in a variety of experiments (e.g. tests of fundamental symmetries, dipolar BECs, quantum information processing, ...). All of these experiments require control over the molecular states. In this talk we will discuss ways of transferring population between various molecular levels. By solving the time-dependent Schrödinger equation using a split-operator approach, we calculate transfer efficiencies for a STIRAP type process. We will consider the examples of KRb (transfer between triplet and singlet ground state) and NaCs (transfer from higher excited vibrational levels of the singlet ground state to lower vibrational levels).

10:54AM P4.00003 Electrostatic trapping of ultracold NaCs molecules, JAN KLEINERT, CHRIS HAIMBERGER, PATRICK ZABAWA, NICHOLAS BIGELOW, University of Rochester — We present an electrostatic trap for ultracold polar molecules. As the molecules are created inside the trap via photoassociation, a continuous accumulation of polar molecules is straightforward. Careful choice of experimental parameters allows detection of specific rovibrational states.

11:06AM P4.00004 Feshbach resonances and photoassociation in heteronuclear systems, MARKO GACESA, PHILIPPE PELLEGRINI, ROBIN CÔTÉ, University of Connecticut — Feshbach resonances have been observed in recent experiments [1] with two different atomic species involving Bose-Fermi mixtures. Such experiments allow the study of new phenomena such as boson-mediated Cooper pairing, the formation of heteronuclear molecules, or degenerate gases with long range dipole-dipole interactions. We studied the scattering properties of mixed alkali gases in the presence of a magnetic field, focusing our attention on systems that include Li, such as Li-Na, Li-Cs or Li-Rb. Several Feshbach resonances were found for experimentally accessible magnetic fields. We also analyzed the production of ultracold ground state molecules via photoassociation in the vicinity of those Feshbach resonances, and found a substantial enhancement of molecule formation in deeply bound levels. For this work, new accurate \textit{ab initio} potentials have been used. [1] S. Inouye et al. Phys. Rev. Lett. 93, 183201 (2004). C.A. Stan et al. Phys. Rev. Lett. 93, 143001 (2004)

1\textsuperscript{1}Supported by NSF and DOE.

11:18AM P4.00005 Production and Trapping of Ultra-cold RbCs Molecules, ERIC HUDSON, NATHAN GILFOY, Department of Physics, Yale University, New Haven, Connecticut 06520, USA, JEREMY SAGE, MIT Lincoln Laboratory, Lexington, MA 02420, USA, SUNIL SAINIS, Department of Mechanical Engineering, Yale University, New Haven, Connecticut 06520, USA, DAVID DEMILLE, Department of Physics, Yale University, New Haven, Connecticut 06520, USA — Our lab has recently demonstrated the production of ultracold polar RbCs molecules in their vibronic ground state, via photoassociation of laser-cooled atoms followed by a laser-stimulated state transfer process. The resulting sample of $X^1Σ^+(v = 0)$ molecules has a translational temperature of $\sim 100 \mu K$ and a narrow distribution of rotational states. With this method it should be possible to produce samples even colder in all degrees of freedom, as well as other bialkali species. Currently, we are implementing a quasi-electrostatic trap (QUEST) to collect the photoassociated molecules for further observation. Specifically, we wish to observe the strong, anisotropic collisions of these polar molecules as a function of an additional static, external electric field. We will report on our progress towards observing these collisions as well as our efforts to implement stimulated Raman adiabatic passage to improve the transfer efficiency of the molecules to the absolute ground state.

11:30AM P4.00006 Determination of the scattering length of the $\text{a}^{3}Σ^+$ potential of $^{87}$RbCs, E. TIESINGA, NIST, E. ARIMONDO, University of Pisa, Italy, M. ANDERLINI, INFN, Florence, Italy — We have determined the scattering length of the $\text{a}^{3}Σ^+$ potential of $^{87}$RbCs based on experimental observations from the literature and the known value for the long-range dispersion coefficient. Our analysis uses quantum defect theory and analytical solutions of the Schrödinger equation for a van der Waals potential. We find that the scattering length is either $\approx 700 \pm 176 \text{ a}_0$ or $176 \pm 2 \text{ a}_0$ with more confidence associated to the first value, where $\text{a}_0=0.05292 \text{ nm}$ is a Bohr radius. An independent value of the van der Waals coefficient could not be determined and the best theoretically determined $\text{C}_6$ value was used.

11:42AM P4.00007 Magneto-electrostatic trapping of Stark decelerated OH, BRIAN SAWYER, BENJAMIN LEV, ERIC HUDSON, BENJAMIN STUHL, MANUEL LARA, JOHN BOHN, JUN YE, JILA/NIST/Univ. of Colorado — Cold molecules promise to impact research on precision measurement, quantum physics, and controlled chemistry. To accomplish this goal, our research employs a Stark decelerator to slow a supersonic expansion of OH in its rovibronic ground state. At the decelerator’s terminus, a <50 mK OH packet of density $10^{14} \text{ cm}^{-3}$ is caught and confined in a magnetic quadrupole trap. An adjustable electric field of sufficient magnitude to completely polarize the OH is superimposed on the trap in either a quadrupole or homogenous field geometry. The trap dynamics deviate from that governed by simple addition of the fields’ forces on OH’s magnetic and electric dipoles. Rather, the OH is confined by potentials modified by molecular state mixing induced by the crossed electric and magnetic fields, which we model via an effective molecular Hamiltonian that includes Stark and Zeeman terms. Confinement of cold polar molecules in a magnetic trap, leaving large, adjustable electric fields for control, is an important step towards the study of low energy dipole-dipole collisions.

\textsuperscript{1}We acknowledge DOE, NRC, NSF, NIST for support.
11:54AM P4.00008 Influence of external fields in cold collisions of OH with Rb1, MANUEL LARA, JILA, JOHN L. BOHN, JILA, University of Colorado and Physical Engineering, Czech Technical University, PAVEL SOLDAN, Doppler Institute, Czech Technical University, JEREMY M. HUTSON, Department of Chemistry, University of Durham — OH molecules in their ground electronic state have been successfully slowed to temperatures of the order of 10 mK by Stark deceleration in at least two laboratories. Cooling the molecules further using ultracold Rb (“sympathetic cooling”) seems an attractive possibility, since Rb is easily cooled and trapped in copious quantities. In previous work, we studied Rb + OH collision processes in the absence of external fields and showed that the cross sections are likely to be unfavorable for sympathetic cooling. Nevertheless, the effects of external magnetic and electric fields are of considerable interest. Here we discuss the results of quantum collision calculations on Rb + OH, accounting for the hyperfine structure of both partners. We use a system of coupled diabatic potential energy surfaces, built from accurate ab initio electronic structure calculations, and expand the scattering wave function in a set of channels suitable for representing the OH levels in the presence of electric and/or magnetic fields. The large number of scattering channels involved is managed through the use of a frame-transformation procedure.

1This work was supported by the NSF.

12:06PM P4.00009 Cold collisions of magnetically oriented YbF molecules in an electric field, T.V. TSCHERBUL, Dept. of Chemistry, University of British Columbia, Vancouver, Canada, J. KLOOS, Dept. of Chemistry and Biochemistry, University of Maryland, College Park, MD, L. RAJCHEL, Dept. of Chemistry, Oakland University, Rochester, MI, R.V. KREMS, Dept. of Chemistry, University of British Columbia, Vancouver, Canada — The sensitivity of spectroscopic experiments to measure the electric dipole moment of the electron can be greatly enhanced by employing dense cold ensembles of heavy polar molecules such as YbF [1]. In order to elucidate the collisional stability of Zeeman states of heavy polar molecules, we have performed a rigorous quantum study of YbF–He collisions in the presence of superimposed electric and magnetic fields. It is shown that the interaction between the ground \( N = 0 \) and the second excited \( N = 2 \) rotational levels is responsible for simultaneous collisional depolarization of electronic and nuclear spins. The nuclear spin-conserving electronic spin relaxation occurs by a two-step mechanism, via the coupling with the \( N = 1 \) rotationally excited state. Both processes are influenced by Feshbach resonances whose positions and lifetimes can be manipulated by varying external electric and magnetic fields. Our results suggest that buffer gas cooling of heavy polar molecules in a magnetic trap may be easier than was previously expected. J.J. Hudson et al., Phys. Rev. Lett. 89, 023003 (2002).

12:18PM P4.00010 Ultracold vibrational relaxation of \( \text{H}_2 \) molecules1, GOULVEN QUÉMÉNER, T. J. DHILIP KUMAR, BALAKRISHNAN NADUVALATH, Department of Chemistry, University of Nevada Las Vegas, Las Vegas, NV 89154, TECK-GHEE LEE, Physics Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831, ROMAN KREMS, Department of Chemistry, University of British Columbia, Vancouver, Canada — The success in creating Bose-Einstein condensates of molecules has spurred much interest in atom-molecule and molecule-molecule collisions at cold and ultracold temperatures. To understand the effect of rotational and vibrational relaxation in molecular collisions at ultracold temperatures we have performed quantum scattering calculations taking the \( \text{H}_2-\text{H}_2 \) system as an illustrative example. We have used a time-independent quantum formalism based on Jacobi coordinates in space fixed frame implemented in a new quantum scattering code [1] that includes all six internal degrees of freedom. Elastic and inelastic cross sections including state-to-state cross sections in cold and ultracold \( \text{H}_2 \) collisions \( (v=1,j=0) + \text{H}_2(v=0,j=0) \) and \( \text{H}_2(v=1,j=0) + \text{H}_2(v=1,j=0) \) collisions will be presented.

1R. V. Krem, TwoBC - quantum scattering program, University of British Columbia, Vancouver, Canada. (2006)

12:30PM P4.00011 Pseudo-potential treatment of two aligned dipoles under external harmonic confinement1, KRITTIKA KANJILAL, Department of Physics and Astronomy, Washington State University, Pullman, WA 99164-2814, JOHN BOHN, JILA, NIST and Department of Physics, University of Colorado, Boulder, CO 80309-0440, DOERTE BLUME, Department of Physics and Astronomy, Washington State University, Pullman, WA 99164-2814 AND JILA, University of Colorado, Boulder, CO 80309-0440 — Dipolar Bose and Fermi gases, which are currently being studied extensively experimentally and theoretically, interact through anisotropic, long-range potentials. Here, we replace the long-range potential by a zero-range pseudo-potential that simplifies the theoretical treatment of two dipolar particles in a harmonic trap. Our zero-range pseudo-potential description reproduces the energy spectrum of two dipoles interacting through a shape-dependent potential under external confinement very well, provided that sufficiently many partial waves are included, and readily leads to a classification scheme of the energy spectrum in terms of approximate angular momentum quantum numbers. The results may be directly relevant to the physics of dipolar gases loaded into optical lattices.

1K. Kanjilal and D. Blume aknowledge support by the NSF through grant PHY-0555316 and J. Bohn by the DOE.

12:42PM P4.00012 Ultracold collisional properties of weakly-bound \( p \)-wave molecules in a gas of spin-polarized fermions, JOSE P. D’INCAO, JILA, University of Colorado, Boulder, CHRIS H. GREENE, Department of Physics and JILA, University of Colorado, Boulder — Abstract: We study three-atom collisional physics relevant to spin-polarized fermionic molecules, under conditions where the interatomic interactions are strongly modified by the presence of a Feshbach resonance [1]. We have explored how both the size and binding energy of \( p \)-wave molecules modify their collisional properties. We also have studied the effects of a non-negligible energy dependence, and of the finite atom-atom \( p \)-wave scattering length, on the \( s \)-wave elastic atom-dimer scattering length. We then speculate about the relevance of these results to ultracold spin-polarized fermi gas experiments. [1] H. Suno, B. D. Esry, and C. H. Greene, Phys. Rev. Lett. 90, 053202 (2003). This work was supported in part by the National Science Foundation.

12:54PM P4.00013 Cold collisions between NH molecules and Rubidium atoms, L. PAUL PARAZZOLI, JOHN OBRECHT, NOAH FITCH, DANIEL LOBSER, CARRIE WEIDNER, HEATHER LEWANDOWSKI, University of Colorado — In the past decade, cooling and trapping of atoms has allowed physicists to probe the nature of quantum mechanics on a macroscopic scale. Recently, ground state molecules have been cooled into the milli-Kelvin regime using a variety of techniques. However, these methods do not produce molecular samples with the required densities and temperatures to see quantum statistical effects. One method that may make this possible is sympathetically cooling the molecules through collisions with laser-cooled atoms. To this end, we are investigating the interactions of cold NH (\(^1\Delta\)) radicals with laser-cooled rubidium. A beam of cold NH radicals is created by supersonic expansion and decelerated using time varying inhomogeneous electric fields. The cold NH is then loaded into an electrostatic trap, which is overlaid spatially with a magnetic trap containing cold rubidium atoms for subsequent collision studies.

Friday, June 8, 2007 10:30AM - 12:30PM – Session P5 Interactions of Ultrashort Intense Light with Atoms, Molecules, and Plasmas TELUS Convention Centre Macleod A3-A4
10:30AM P5.00001 High Harmonic Generation from Non-symmetric Molecular Targets in a Hollow-Core Waveguide\textsuperscript{1}, BRETT SICKMILLER, ROBERT JONES, Physics Department, University of Virginia — We explore high harmonic generation (HHG) from gas-phase molecules in hollow-core waveguide driven by intense 2-color (400nm+800nm) laser pulses. For symmetric molecules and fields, parity conservation precludes the generation of even harmonics. However for non-symmetric molecules such as CO, the predicted preference for ionization from the C rather than O site should allow for the generation of even harmonics using a symmetric fundamental laser field. Unfortunately, in a macroscopic way, the random orientation results in a cancellation of the even-harmonics produced by individual molecules within the ensemble. We are attempting to transiently orient CO molecules in a waveguide by impulsively kicking them with a short, asymmetric 2-color laser pulse, creating an ensemble of rotational wavepackets without definite parity. We monitor the production of even harmonics generated by a 30 fs 800 nm laser pulse as a function of its delay after the 2-color pump. Liquid nitrogen cooling of the waveguide improves the achievable degree of alignment and orientation.

\textsuperscript{1}Acknowledgement Support from DOE

10:42AM P5.00002 Imaging Molecular Orbitals with Ultrashort Intense Laser Pulses \textsuperscript{1}, ANDRE D. BANDRAUK\textsuperscript{1}, Univesite de Sherbrooke, GERARD LAGMAGO KAMTA\textsuperscript{2}, McGill University, MOLECULES IN INTENSE LASER FIELDS TEAM — Exact 3-D numerical solutions of the time-dependent Schroedinger equation, TDSE, for the one-electron H2+(D2+) molecule in the Born Oppenheimer (fixed nuclei) approximation have been obtained to calculate the angular dependence of ionization rates as a function of internuclear distance in the presence of ultrashort (5 fs) intense (I \textsuperscript{10}14 W/cm\textsuperscript{2}) 800 nm laser pulses. It is shown that the ionization rates reproduce well the molecular orbital symmetries and structures near equilibrium whereas at larger internuclear distances where CREI (Charge Resonance Enhanced Ionization) occurs considerable deviation of orbital structure occurs due to “off-axis” tunnelling ionization. The results show that intense low frequency ultrashort pulses can image molecular orbitals provided molecules can be properly aligned.

\textsuperscript{1}Canada Research Chair \textsuperscript{2}Medical Physics Dept.

10:54AM P5.00003 Coherence Effects in Intense Laser Pulse Dissociative Ionization of H 2+ \textsuperscript{1}, ANDRE D. BANDRAUK\textsuperscript{1}, SCZEPAN CHELKOWSKI, Universite de Sherbrooke, MOLECULES IN INTENSE LASER FIELDS TEAM — Numerical solutions of the time-dependent Schroedinger equation (TDSE) for non-Born Oppenheimer H2+(D2+) in 20-100 fs intense laser pulses are presented to interpret structure observed in the Coulomb-Explosion (CE) spectra during dissociative ionization of the above molecules (Staudte-Corkum, NRC)\textsuperscript{[1]}. Detailed dissociative ionization and CE simulations with a non Born Oppenheimer code\textsuperscript{[2]} at different wave lengths and intensities allow to establish the mechanism for such structure in the CE spectra as due to interference between coherent one and two photon electronic excitation. Increasing intensity leads to “localization” of the active electron at the peaks of the electric field of the pulse. “Attosecond” electron ionization at these peaks produces structures in the CE spectra from an interfering coherent superposition of nuclear wave packets on different potential surfaces. The dissociative ionization simulations confirm this as a novel nonlinear coherent electron-nuclear interference phenomenon. \textsuperscript{[1]} A Staudte et al, Phys Rev Lett, in press (2207); \textsuperscript{[2]} A D Bandrauk, S Chelkowski, Phys Rev Lett 84, 3562(2000): 87, 273004(2002).

\textsuperscript{1}Canada Research Chair

11:06AM P5.00004 Relativistic ionization and rescattering, MICHAEL KLAIBER, KAREN HATSAGORTSYAN, ROBERT FISCHER, MANFRID LEIN, MARIO VERSCHL, CHRISTOPH H. KEITEL, Max-Planck-Institute for Nuclear Physics, Saupfercheckweg 1, D-69117 Heidelberg — In the relativistic regime the magnituded induced drift of the ionized electron severely suppresses the probability of the electron revisiting the ionic core and, consequently, the yield of harmonic photons. We propose several methods to increase the efficiency of rescattering in the relativistic regime. In the weakly relativistic regime, we demonstrate that the relativistic drift of the electron can be efficiently harnessed to enhance the recollisions of electrons from molecular orbitals with mirror asymmetry\textsuperscript{[1]}. In the strong relativistic regime, we show how efficient recollisions are feasible by employing strong laser pulses which are specially tailored as attosecond pulse trains\textsuperscript{[2]}. For experimental realization it is more advantageous to employ counter-propagating attosecond pulse trains. This way the energies of the revisiting electron at the atomic core can reach the MeV domain, thus rendering hard x-ray harmonics and nuclear reactions with single atoms feasible. Other recollision schemes proposed are based on two consecutive counterpropagating laser pulses\textsuperscript{[3]} and magnetic field. References: \textsuperscript{[1]} R. Fischer et al., Phys. Rev. Lett. 97, 143901 (2006). \textsuperscript{[2]} M. Klaiber, et al., Phys. Rev. A, 74, 051803(R) (2006). \textsuperscript{[3]} M. Verschl, and C. H. Keitel, J. Phys. B, in press.

11:18AM P5.00005 Intramolecular Dynamics Probed using High Harmonic Generation, ROBYNNE HOOPER, XIBIN ZHOU, WEN LI, NICK WAGNER, HENRY KAPTEYN, MARGARET MURNANE, JILA — We observed intramolecular dynamics as a modulation in high harmonic emission. We excite coherent vibrations in CF\textsubscript{2}Cl using impulsive Raman scattering with a short laser pulse. A second laser pulse generates high harmonics. The harmonic yield is observed to oscillate at frequencies corresponding to three vibrational modes of CF\textsubscript{2}Cl. In a second experiment, we used UV light to excite and dissociate CF\textsubscript{3} and follow the dynamic evolution by monitoring the harmonic yield. We observe a large modulation of the harmonic yield, likely due to resonance excitation and subsequent dissociation of the molecule. We speculate that the less-than full baseline recovery after the UV pulse is due to ionization, and that the harmonic yield is sensitive to the bond length during dissociation. By these two experiments, we confirm that high harmonic generation is a sensitive probe of intramolecular dynamics and may yield more information simultaneously than conventional ultrafast spectroscopic techniques.

11:30AM P5.00006 ABSTRACT HAS BEEN MOVED TO Q2.00009

11:42AM P5.00007 Does Wave-Packet Spreading Influence Light Scattering from Free Electrons in an Intense Laser Field? \textsuperscript{1}, JUSTIN PEATROSS, Brigham Young University — Arguments are presented against treating electron quantum probability current as a classical current distribution for purposes of computing light emission. This procedure, apparently widely accepted within the high-intensity laser community, leads to the startling prediction that light scattered from a free electron quickly diminishes when the electron wave packet spreads to the scale of the driving-field wavelength. One draws the absurd conclusion that a single electron phase-matches (and phase-mismatches) with itself when emitting light. This question can be put to the test: The outcome of this dispute dramatically impacts the amount of light expected to scatter out the side of a relativistic laser beam.

\textsuperscript{1}Canada Research Chair
11:54AM P5.00008 Electromagnetically induced transparency for x-rays1, CHRISTIAN BUTH, ROBIN SANTRA, LINDA YOUNG, Argonne National Laboratory, Argonne, Illinois 60439, USA — We discuss electromagnetically induced transparency (EIT) for x-rays in laser-dressed neon. We use a newly devised ab initio theory to calculate the x-ray photoabsorption cross section and the x-ray polarization of a neon atom dressed by an optical laser (800 nm, 10\(^{13}\) W cm\(^{-2}\)) with a photon energy close to the 1s\(^{-1}\)3s \(\rightarrow\) 1s\(^{-1}\)3p transition. The results are investigated further in terms of an exactly solvable \(\Lambda\)-type three-level model where we point out the need for an intense dressing laser due to the femtosecond lifetime of core-excited neon. Practical experimental realization of EIT for x-rays is discussed and potential applications are outlined. This work opens new opportunities for research with ultrafast x-ray sources.

1C.B. is self-employed (Germany) and was funded by a Feodor Lynen Research Fellowship from the Alexander von Humboldt Foundation. R.S.’s work was supported by the Office of Science, U.S. Department of Energy, under Contract No. DE-AC02-06CH11357

12:06PM P5.00009 A Direct, Time Dependent, Lanczos Propagation Method for Non-Orthogonal Basis Sets, BARRY I. SCHNEIDER, Physics Division, NSF, Arlington, VA 22230 and Electron and Optical Physics Division, NIST, Gaithersburg, MD 20899, XIAOXU GUAN, Drake University, Des Moines, IA 50311, JOHANNES FEIST, Institute for Theoretical Physics, Vienna University of Technology, A1040, Vienna, Austria, KLAUS BARTSCHAT, Drake University, Des Moines, IA 50311, CLIFF NOBLE, CSED, Daresbury Laboratory, WA4 4AD, UK, OLEG ZATSARINNY, Drake University, Des Moines, IA 50311 — We have developed an efficient approach for solving the time-dependent Schroedinger equation for the interaction of a strong laser pulse with a general atom, when the many-electron basis set is non-orthogonal. The propagation equations have the form, i\(S\frac{dC(t)}{dt} = HC(t)\) where \(S\) and \(H\) are respectively the overlap and Hamiltonian matrices in the many-electron space. By a succession of Lanczos orthogonalizations, the Hamiltonian is reduced to tri-diagonal form, but the overlap matrix remains full in the small, Lanczos basis. Thus, we are faced with solving a small, generalized eigenvalue problem at each step of the Lanczos recursion. The approach is still dominated by the need to find an efficient way to multiply the \(H\) and \(S\) matrix on a vector. Some examples of the new method will be presented in the talk.

12:18PM P5.00010 Vibrational stabilization of cold molecules using a phase coherent train of ultrashort pulses, AVI PE’ER, JILA, University of Colorado, EGVENY SHAPIRO, University of British Columbia, MATTHEW C. STOWE, JILA, University of Colorado, MOSHE SHAPIRO, University of British Columbia, JUN YE, NIST and JILA, University of Colorado — Ultracold molecules can be created from atoms by Feshbach resonance techniques. While these molecules are in the electronic ground state, they are highly excited vibrationally. As a result, these molecules are unstable due to vibrational quenching. We present a general and highly efficient scheme for vibration stabilization using a coherent train of weak pump-dump pairs of shaped ultrashort pulses to perform narrow-band Raman transitions between vibrational levels. The use of weak pulses permits an analytic description within the framework of coherent control in the perturbative regime, while coherent accumulation of many pulse pairs enables near unity transfer efficiency with a high spectral selectivity, thus forming a powerful combination of pump-dump control schemes and the precision of the frequency comb. The feasibility and robustness of this concept is verified by realistic simulations of the molecular dynamics.

Friday, June 8, 2007 10:30AM - 12:42PM — Session P6 Photon Interactions with Atoms and Molecules TELUS Convention Centre Olde Scotch Room

10:30AM P6.00001 Double Photoionization of H\(^{-}\) by a Single Photon1, FRANK YIP, UC Berkeley/LBNL, DANIEL HORNER, LANL, C. WILLIAM MCCURDY, UC Davis/LBNL, THOMAS RESCIGNO, LBNL — We present fully differential cross sections for the three-body breakup of H\(^{-}\) by single photon absorption. Electron correlation drives the double photoionization process and thus should impact double photoionization results most strongly for H\(^{-}\), which is a three-body atomic system bound only because of electron correlation. The absolute triple-differential and single-differential cross sections were obtained from ab initio calculations making use of exterior complex scaling within a discrete variable representation partial wave basis. Results calculated at photon energies of 18eV and 30eV are compared with reported cross sections for helium calculated at 20eV above the double ionization threshold.

1Performed under auspices of USDOE by LBNL and supported by DOE OBES Division of Chemical Sciences.

10:42AM P6.00002 Perturbative and Non-Perturbative Calculations of Photoionization of H\(^{+}\)1, M. FOSTER, J. COLGAN, Los Alamos National Laboratory, Theoretical Division, O. HAGAN, J.L. PEACHER, D.H. MADISON, University of Missouri - Rolla, M.S. PINDZOLA, Auburn University — We present both non-perturbative and perturbative calculations for photoionization of H\(^{+}\). For the perturbative approach, we have investigated two different final state wavefunctions for the ionized electron. The first wavefunction is a product of two Coulomb functions (2C) where each Coulomb function represents the two-body interaction between the ionized electron and one of the residual protons in the nucleus. The second final state wavefunction, we investigated was a distorted wave for the ionized electron calculated using a spherically symmetric potential for the two residual protons. These methods are compared to the results computed using the non-perturbative time-dependent method. The time-dependent method solves the time-dependent Schroedinger equation for H\(^{+}\) using the variational principle in spherical coordinates centered on the center of mass of the H\(^{+}\) system.

1US Department of Energy through Los Alamos National Laboratory and grant to Auburn University, NSF grant PHY-0456528

10:54AM P6.00003 Production of Excited Atomic Hydrogen and Deuterium from H\(_{2}\) and D\(_{2}\) Photodissociation, T.J. GAY, University of Nebraska-Lincoln, J.D. BOZEK, LBNL, J.E. FURST, University of Newcastle-Ourimbah, H. GOULD, A.L.D. KILCOYNE, LBNL, J.R. MACHACEK, University of Nebraska-Lincoln, F. MARTIN, Universidad Autonoma de Madrid, K.W. MCLAUGHLIN, Loras College, J.L. SANZ-VICARIO, Universidad de Antioquia — We have measured the production of both \(\text{Li}^{+}\) and \(\text{H}^{+}\) fluorescence from atomic H and D for the photodissociation of \(\text{H}_{2}\) and \(\text{D}_{2}\) by linearly-polarized photons with energies between 24 and 60 eV. In this energy range, excited photofragments result primarily from the production of doubly-excited molecular species which promptly autoionize or dissociate into two neutrals. Our data are compared with ab initio calculations of the dissociation process, in which both doubly-excited state production and prompt ionization through non-resonant channels are considered. Agreement between our experimental data and that of earlier work [1], and with our theoretical calculations, is qualitative at best. [1] E.Melero García, J.Álvarez Ruiz, S.Mennuhr, E.Rachlew, P. Erman, A.Kivimäki, M.Glass-Maujean, R.Richter, and M.Coreno, J.Phys.B 39, 205 (2006). Support provided by the NSF (Grant PHY-0354946), DOE (LBNL/ALS) and ANSTO (Access to Major Research Facilities Programme).
1:18AM P6.00005 Global Franck-Condon breakdown: nonresonant molecular photoionization processes

11:30AM P6.00006 X-Ray Absorption in Carbon Ions Near the K-Edge

11:42AM P6.00007 Low energy valence photoionization of Ar confined in C_{60}

11:54AM P6.00008 Half-filled shell atoms as intense sources of spin-polarized photoelectrons

1:06PM P6.00009 Electron-Ion Recombination, Photoionization and Dielectronic Satellite Lines of Ca XVIII and Ca XIX Using Unified Method
surfaces do not prevent pairing but quench the superfluid state, thus realizing a system of fermion pairs that do not condense even at the lowest temperature.

pairing in the normal and superfluid phases of a strongly interacting Fermi gas with imbalanced spin populations. At high spin imbalances the system cannot

SCHUNCK, YONG-IL SHIN, ANDRE SCHRÖTZEK, MARTIN ZWIERLEIN, WOLFGANG KETTERLE, MIT — We use radio-frequency spectroscopy to study

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diagram.

phases is continuous, resulting in a partially polarized shell structure, without distortion. These observations are consistent with a tricritical point in the phase

atomic scattering resonances, called Feshbach resonances, have been used to create molecular Bose-Einstein condensates and

atomic gas may also be varied by creating a population imbalance of the two components.

interactions via a Feshbach resonance has enabled the realization of the BEC-BCS crossover in a two component Fermi gas. The spin polarization of an

physics. In addition to being clean and well-characterized, the physical parameters of ultracold atomic gases are readily tunable. Notably, the tunability of

Ultracold atomic fermions hold great promise for simulating important, and in some cases, unsolved models of condensed matter

or a (FFLO) phase with nonzero momentum Cooper pairs. Their qualitative properties and the associated experimental signatures are outlined.

universal thermodynamic and dynamic properties at resonance is discussed. In the spin imbalanced situation, novel phases appear like a ‘magnetized’ superfluid

works supported by DOE, ARO, and NSF

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2:06PM Q1.00002 Universality and novel phases in the BCS-BEC crossover , WILHELM ZWERGER, Physik

Department TU Munich — We discuss the BCS-BEC crossover in a degenerate Fermi gas near a Feshbach resonance. The origin and experimental verification of universal thermodynamic and dynamic properties at resonance is discussed. In the spin imbalanced situation, novel phases appear like a ‘magnetized’ superfluid or a (FFLO) phase with nonzero Momentum Cooper pairs. Their qualitative properties and the associated experimental signatures are outlined.

2:42PM Q1.00003 Pairing of Fermions with Unequal Spin Populations , RANDALL G. HULET\textsuperscript{1}, Rice University and Rice Quantum Institute — Ultracold atomic fermions hold great promise for simulating important, and in some cases, unsolved models of condensed matter physics. In addition to being clean and well-characterized, the physical parameters of ultracold atomic gases are readily tunable. Notably, the tunability of interactions via a Feshbach resonance has enabled the realization of the BEC-BCS crossover in a two component Fermi gas. The spin polarization of an atomic gas may also be varied by creating a population imbalance of the two components\textsuperscript{2} \textsuperscript{3} \textsuperscript{4} \textsuperscript{5} I will discuss our in-situ measurements of the real-space density distributions of polarized mixtures of \textsuperscript{6}Li atoms.\textsuperscript{6} We identify three distinct phases: two contain an unpolarized, fully paired core, while the third is the polarized normal phase. At the lowest temperatures, the gas phase separates into an unpolarized superfluid core with the unpaired atoms residing in a fully polarized normal shell. In this case, the boundary between the superfluid and normal phases is sharp, consistent with a first-order phase transition, and the core is distorted by what is believed to be surface tension between the superfluid and normal components. At slightly higher temperature, the transition between the phases is continuous, resulting in a partially polarized shell structure, without distortion. These observations are consistent with a tricritical point in the phase diagram.

1Work done in collaboration with G.B. Partridge, Wenhui Li, Y.A. Liao, R.I. Kamar, M. Haque, and H.T.C. Stoof.


3:18PM Q1.00004 An atomic Fermi gas near a p-wave Feshbach resonance , DEBORAH JIN, JILA, NIST

and University of Colorado — Atomic scattering resonances, called Feshbach resonances, have been used to create molecular Bose-Einstein condensates and Fermi superfluids. Past work has focused on s-wave, or non-rotating, pairs created from two fermionic atoms. I will report on investigations of pair creation in an ultracold Fermi gas of potassium-40 atoms near a p-wave Feshbach resonance.

3:54PM Q1.00005 Pairing of Strongly Interacting Fermions without Superfluidity\textsuperscript{1}, CHRISTIAN SCHUNCK, YONG-IL SHIN, ANDRE SCHRÖTZEK, MARTIN ZWIERLEIN, WOLFGANG KETTERLE, MIT — We use radio-frequency spectroscopy to study pairing in the normal and superfluid phases of a strongly interacting Fermi gas with imbalanced spin populations. At high spin imbalances the system cannot become superfluid even at zero temperature. In this normal phase full pairing of the minority atoms is observed. This demonstrates that mismatched Fermi surfaces do not prevent pairing but quench the superfluid state, thus realizing a system of fermion pairs that do not condense even at the lowest temperature.

1This work was supported by NSF and ONR.
Friday, June 8, 2007 1:30PM - 4:06PM –
Session Q2 Focus Session: The Ultra Intense Laser Frontier

TELUS Convention Centre Macleod C

1:30PM Q2.00001 High Energy Density Physics with the Texas Petawatt Laser and a Look Toward Exawatt Lasers , TODD DITMIRE, University of Texas — Using a combination of high peak power chirped pulse amplification technologies we are developing a unique petawatt peak power laser at the University of Texas. One of the new frontiers opened by a lasers like the Texas Petawatt is in high energy-density (HED) science. The Texas Petawatt will deliver 100 fs pulses with energy of over 200 J. In this talk I will discuss some of the recent experiments in high energy density science we have conducted using existing high intensity short pulse lasers with illustrative examples that point to applications on the Texas Petawatt. These areas of HED investigation include exotic physics such Gbar pressures in heated solids, radiative hydrodynamics and nuclear fusion. I will, for example, discuss experiments on isochoric heating of solid targets for high temperature and pressure equation of state measurements. I will examine some of the ways that plasma and hydrodynamic regimes of astrophysical significance can be accessed with petawatt-class lasers. I will also discuss applications in the generation of ultrafast, bright bursts of radiation including x-rays, protons and fast neutrons. Finally, I will discuss how the technology being implemented in the Texas Petawatt could be scaled to the exawatt peak power level in a straightforward way.

2:06PM Q2.00002 Classical Ensemble Studies of Double Ionization at 390 nm , S.L. HAAN, Z.S. SMITH, Calvin College — An ensemble of 400,000 classical 3d atoms is employed to investigate double ionization of helium for laser wavelength 390 nm and intensity 1.1PW/cm². It has previously been shown by Parker et al. [1] that electrons of energy above 2U consist of two recollision sequences, one of which can be described as excitation-backscatter-escape and the other as recapture ionization with prompt nuclear scattering. It is shown how the nuclear and laser forces combine in each case to give an electron–usually the struck electron–final energy above the usual 2U, cap. [1] J. S. Parker, et al., Phys. Rev. Lett. 96, 133001 (2006).

2:18PM Q2.00003 Intense field ionization of methane, butane, and octane: transition from molecular to atomic response , SASIKUMAR PALANIYAPPAN, ROBERT MITCHELL, ROBERT SAUER, BARRY WALKER, Department of physics and astronomy, University of Delaware, Newark, DE 19716 — We quantify electron wavefunction interference effects on radiation by calculating the angle- and energy-resolved Larmor radiation from atomic ionization in the focus of ultra-intense field. Our calculations use a semi-classical, trajectory ensemble model of ionization for intensities in the range of 10^16 to 10^20 W/cm^2. For non-relativistic intensities, including the quantum nature of ionization decreases the radiation by an order of magnitude due to destructive interference effects in the extended probability of the electron wavefunction and the quantum nature of ionization. The interference effect is largest for high energy photons since ionization extends to a spatial width of ~300nm and electron quiver width is ~1μm. Our results also show the decrease in radiation due to the quantum nature of an electron is larger when emitted photons are observed in the laser polarization direction than in the propagation direction.

2:30PM Q2.00004 Quantum Interference Effects In Radiation From Atomic Ionization In Ultra-high Fields , ISAAC GHEBREGZIABHER, B.C. WALKER, Department of Physics and Astronomy, University of Delaware, Newark, DE 19716 — We quantify electron wavefunction interference effects on radiation by calculating the angle- and energy-resolved Larmor radiation from atomic ionization in the focus of ultra-intense field. Our calculations use a semi-classical, trajectory ensemble model of ionization for intensities in the range of 10^16 to 10^20 W/cm^2. For non-relativistic intensities, including the quantum nature of ionization decreases the radiation by an order of magnitude due to destructive interference effects in the extended probability of the electron wavefunction and the quantum nature of ionization. The interference effect is largest for high energy photons since ionization extends to a spatial width of ~300nm and electron quiver width is ~1μm. Our results also show the decrease in radiation due to the quantum nature of an electron is larger when emitted photons are observed in the laser polarization direction than in the propagation direction.

2:42PM Q2.00005 First light from the Diocles laser: Relativistic laser-plasmas and beams , DONALD UMSTADTER, University of Nebraska, Lincoln — Reported are first experimental results from a new high-power (150 TW) laser, Diocles, now in operation at the University of Nebraska, Lincoln. Discussed are novel approaches to using the ultra-high-intensity light from this laser to study relativistic laser plasma interactions. Bright, ultrashort duration (femtosecond) pulses of energetic (keV – MeV) x-ray and charged-particle beams are generated through these interactions. Also covered in this talk will be applications of these unique radiation sources for research in the physical sciences, as well as biomedicine, defense and homeland security.
Measurements of ultraintense ultrafast laser pulse electron acceleration through analysis of radioactive products. Rapid progress has recently been achieved in developing techniques to controllably accelerate charged particles to relativistic energies using plasma wake fields generated in gas or dense media using ultraintense ultrafast laser pulses. An inherent technical difficulty in these experiments lies in complications of measuring the energy and angular distributions of large numbers (> 10^9) of 'simultaneously' (~ ps) accelerated particles. We will discuss experimental techniques developed for interrogation of laser accelerated electrons, including methods based on production of radioactive targets.

1 Work supported by the Laboratory Directed Research and Development Program of Oak Ridge National Laboratory, managed by UT-Battelle, LLC, for the U.S. DOE under Contract No. DE-AC05-00OR22725, and the NSF through the Physics Frontier Center FOCUS.

3:30PM Q2.000007 Photoelectron Angular Distributions from an Ultrastrong Field Atom Interaction. — ANTHONY DICHIA, ISAAC GHEBREGZIABHER, ROBERT SAUER, BARRY WALKER, Department of Physics and Astronomy, University of Delaware, Newark DE 19716 — Ultrastrong field laser physics has introduced a new regime for light-matter interactions. Photoelectrons in the continuum acquire relativistic kinetic energy from the laser electric field and the laser magnetic field can no longer be ignored. Therefore, the full Lorentz force is necessary to understand photoelectron continuum dynamics. As a result photoelectrons are pushed toward the direction of laser propagation. This effect impacts processes such as rescattering and high harmonic generation by preventing photoelectrons from revisiting the atomic core. In addition, the large photoelectron velocity could prove useful for laser based accelerator schemes. We report the photoelectron angular distributions measured for Argon atoms at an intensity of 5x10^16 W/cm^2. The experimental apparatus consists of a 780 nm, 45 fs Ti:Sapphire chirped pulse amplifier operating at the terawatt level. The laser is focused in a UHV chamber to a spot of 2 μm in diameter. We find that the isotropy increases with intensity and lower kinetic energy photoelectrons are more isotropic.

5:42PM Q2.00008 Elongation of plasma channel for electron acceleration. — LIMING CHEN, Advanced Photon Research Center, Japan Atomic Energy Agency — Experiments for the laser guiding studies has been carried out with the 30 fs, 100 TW Ti:Sapphire laser pulse interaction with the long slab (1.2x10 mm^3) and discharged capillary of underdense plasma. Formation of extremely long plasma channel with its length (∼ 10 mm) 10 times above the Rayleigh length is observed when the laser pulse power is much higher than the critical power for relativistic self-focusing. The long self-guiding channel formation is accompanied by the quasi-monoenergetic electron acceleration with a low transverse emittance (< 0.8 μm mrad) and high electric current (up to ∼ 10 nC/shot). In order to continuously elongate plasma channel, a 4 cm-scale discharged capillary was used. We successfully demonstrated laser-plasma acceleration of high-quality electron beams up to nearly GeV. Our results exactly verified the prediction of laser-wavefield acceleration through a cm-scale plasma channel in the "blowout bubble" regime, where a micro-scale plasma cavity produced through the ultra-relativistic laser-plasma interactions plays an essential role in the self-injection and acceleration of electrons.

Friday, June 8, 2007 1:30PM - 3:54PM –
Session Q3 Focus Session: Electron-Molecule Collisions TELUS Convention Centre Macleod B

1:30PM Q3.00001 Low Energy Electron Molecule Collisions1 — STEPHEN BUCKMAN, Centre for Anti-Matter Matter Studies, Australian National University — Low energy electron molecule collisions are important in many technological, environmental and biological processes. Electrons are known to be the ‘drivers’ of technological processes based around gas discharges, from lights and lamps to surface processing plasmas. In such environments electrons are responsible for much of the vibrational and electronic excitation that results in photon emissions, for the formation of long-lived metastable species, and for the production of highly reactive free radicals through processes such as dissociative attachment. Electron collisions also play an important role in our atmosphere and those of all planets and stars. In recent years low energy electrons have also been shown to play a vital role in cell and tissue damage caused by ionizing radiation. One of the key goals for collision physics, both experiment and theory, is to provide accurate, absolute cross sections for such low energy charged particle collisions - elastic scattering, vibrational excitation, near-threshold electronic excitation. This talk will focus on some recent advances in these areas. This work is done in collaboration with James Sullivan, Violaine Vizcaino, Stan Newman, Julian Lower, Subhendu Mondal, Chris Colyer, Michael Brunger, Todd Maddern and Leigh Hargreaves.

1 Supported by the Australian Research Council.

2:06PM Q3.00002 Theoretical and Experimental Study of Out-of-Plane Cross Sections for Electron Impact Ionization of He and H21 — OLA AL-HAGAN, D.H. MADISON, University of Missouri-Rolla, CHRISTIAN KAISER, ANDREW MURRAY, University of Manchester — In recent years, sharp disagreement between theory and experiment has been found for heavy particle ionization of He for electrons ejected out of the scattering plane. On the other hand, good agreement was found in the scattering plane. The lack of agreement between experiment and theory for out-of-plane has been attributed to a double scattering mechanism where the projectile first ‘hits’ the electron and then scatters off the nucleus. If these effects are important for a He nucleus, they should be even more important for a H2 nucleus. We will report theoretical and experimental fully differential cross section (FDCS) results for electron impact ionization of both He and H2. Electron ejection both in the scattering plane and out-of-plane will be examined.

1 Work supported by NSF grant PHY-0456528.

1. Funded by a Grant from NSF under the AMOP-RUI program

2:30PM Q3.00004 Electron Impact Induced VUV Emissions from Nitrous Oxide

2:42PM Q3.00005 Intrinsically Polyatomic Phenomena in Electron-Molecule Scattering

3:18PM Q3.00006 Resonances and threshold effects in low-energy electron collisions with methyl halides

3:30PM Q3.00007 The Role of Nuclear Motion in the Photo-Double Ionization of Molecular Hydrogen

1. Supported by NSF, grant No. PHY-0354688.

1. Supported by the DOE Office of Basic Energy Sciences.
3:42PM Q3.00008 The role of nuclear dynamics in molecular ionization processes produced by synchrotron radiation and ultrashort pulses, FERNANDO MARTÍN, Departamento de Química. C-9. Universidad Autónoma de Madrid. 28049-Madrid. Spain. — The important role of nuclear dynamics in molecular ionization processes produced by synchrotron radiation and ultrashort pulses will be demonstrated using accurate ab initio theoretical calculations that account for all electronic and vibrational degrees of freedom. Results for electron angular distributions from fixed-in-space H$_2$ molecules will be presented. For photon energies of a few hundreds of eV, it is shown that, for molecules oriented parallel to the polarization direction, the angular patterns reveal a complex nodal structure, while for molecules oriented perpendicularly, typical Young’s doubleslit interference patterns are observed. These patterns change dramatically as the molecule vibrates. For photon energies of ~ 30 eV, it is shown that the emission of a photoelectron with subsequent dissociation of the remaining H$_2^+$ fragment shows no symmetry with respect to the ionic H$^+$ and neutral H atomic fragments. This lack of symmetry results from the entanglement between symmetric and antisymmetric H$_2^+$ states caused by autoionization. The dependence on pulse parameters of multiphoton ionization of H$_2$ by ultrashort pulses will also be analyzed. Refs: A. Palacios et al., Phys. Rev. Lett. 96, 173201 (2006); J. Fernández et al., Phys. Rev. Lett. 98, 043005 (2007); F. Martín et al., Science 315, 630 (2007).

Friday, June 8, 2007 1:30PM - 3:54PM
Session Q4 Laser Cooling and Trapping
TELUS Convention Centre Macleod A1-A2

1:30PM Q4.00001 A diode laser system for sideband cooling of Sr$^+$, KENNETH BROWN, Department of Chemistry, Georgia Institute of Technology; JAROSLAW LABAZIEWICZ, PHILIP RICHERME, ISAAC CHUANG, Center for Ultracold Atoms, Massachusetts Institute of Technology — Sideband cooling is performed on the $5S_{1/2}$ to $4D_{5/2}$ line of Sr$^+$ in an RF Paul trap using a diode laser system in which the linewidth is reduced by optical feedback and the frequency is stabilized to the ion. The diode laser system uses optical feedback from a filter cavity to narrow the linewidth of an external cavity diode laser to $< 30$ kHz. The frequencies of the sideband cooling (674 nm) and Doppler cooling (422 nm) lasers are stabilized by performing a shelving experiment on the $5S_{1/2}$ to $4D_{5/2}$ carrier transition. This stabilization feedback is included in the pulse sequence used for sideband cooling. Using this scheme, the axial motion is sideband cooled to an average quanta $\langle n\rangle \leq 0.11$ without stabilizing the lasers to a high-finesse cavity.

2:18PM Q4.00005 Optical Stark deceleration of cold molecules, P.F. BARKER, University College London — Our work in this rapidly developing field of cold molecules has centered on the development of optical Stark deceleration, which momentarily traps and brings molecules to rest, initially with a molecular beam. This is done utilizing the large optical potentials that result from the interaction between an induced dipole moment and the intense optical field (10$^{12}$ W/cm$^2$) that induced it. As all molecules are polarizable, in principle any molecule or atom can be manipulated and slowed in the same manner, opening up the capability of creating essentially any cold molecular species. We describe our experiments, where we have successfully slowed every species that we have so far placed within the molecular beam[1-3]. This includes the organic molecule benzene (non-polar) and nitric oxide (weakly polar), as well as ground state xenon, the inert buffer gas used to form the molecular beam. Benzene, at a density of 10$^{11}$ cm$^{-3}$, has been brought to rest using a pulsed optical lattice created by two near counter-propagating optical fields. [1] R. Fulton, A.I. Bishop, P.F. Barker, Phys. Rev. Lett. 93, 243004 (2004) [2] R. Fulton, A. Bishop, M.N. Schneider, P.F. Barker, Nature Physics 2, 465 (2006) [3] R. Fulton, A.I. Bishop, M.N. Schneider, P.F. Barker, J. Phys. B: At. Mol. Opt. Phys. 39, S1097 (2006)

2:30PM Q4.00006 Loading Dynamics and Characteristics of a Far Off-Resonance Optical Dipole Trap, Y.N. MARTINEZ, P.G. MICKELSON, S.B. NAGEL, T.C. KILLIAN, Rice University — We implement an optical dipole trap in a crossed beam configuration for experiments with ultracold strontium. Strontium atoms cooled to nearly 1 $\mu$K are loaded into the optical dipole trap from a magneto-optical trap operating on the 689 nm intercombination line. Loading dynamics and characteristics of the far off-resonance dipole trap are explored as part of our group's study of ultracold collisions in strontium.

1We acknowledge financial support from DOE, NRC, NSF, and NIST

2We acknowledge financial support from DOE, NRC, NSF, and NIST

171Yb and $^{87}$Sr.
2:42PM Q4.00007 Realization of a Magneto-Optical Trap for Cadmium Atoms\textsuperscript{1}. MARK ACTON, KATHY-ANNE BRICKMAN, MING-SIEN CHANG, DZIMITRY MATSIUKIVICH, FOCUS and Physics Dept., Univ. of Michigan, PAUL HALJAN, Physics Dept., Simon Fraser Univ., VANDERLEI BAGNATO, Universidade de Sao Paulo, Instituto de Fisica de Sao Carlos, CHRISTOPHER MONROE, FOCUS and Physics Dept., Univ. of Michigan — We report the confinement of cadmium atoms in a vapor cell magneto-optical trap (MOT). Using the closed \( ^{1}S_{0} \rightarrow ^{1}P_{1} \) transition (\( \lambda = 229 \text{ nm}, \gamma = 2\pi \times 90.9 \text{ MHz} \)), we are able to trap neutral cadmium atoms and examine the dependence of loss mechanisms, atomic density, and atom number on trapping parameters. This represents the trapping of a new atomic species and the shortest wavelength MOT produced to date. We anticipate that cold Cd atoms will be interesting for future studies in at least two directions: First, the \(^{1}S_{0} \rightarrow ^{1}P_{1} \) intercombination lines (\( \lambda = 325 \text{ nm} \)) could be useful for optical cooling to very low temperatures (\(^{1}S_{0} \rightarrow ^{1}P_{1} \)) and for high resolution optical spectroscopy (\(^{1}S_{0} \rightarrow ^{3}P_{1} \)). Second, combining cold Cd atoms with individual laser-cooled \( \text{Cd}^{+} \) ions in a nearby ion trap may allow for studies of cold ion/neutral interactions such as charge-exchange, the transport of a charged “hole” through a gas, and perhaps the transfer of coherence from hyperfine states in the ion to pure nuclear spins in the neutral gas.

\textsuperscript{1}Supported by the National Science Foundation ITR and PIF Programs.

2:54PM Q4.00008 Measurement of Population Dynamics in STIRAP . M.A. GEARBA, Department of Physics and Astronomy, University of Southern Mississippi, Hattiesburg, MS 39406, M.L. TRÁCHY, G. VESHAPIDZE, M.H. SHAH, J.R. MacDonald Laboratory, Kansas State University, Manhattan, KS 66506, H.A. CAMP, Institute for Defense Analyses, Alexandria, VA 22311, H.U. JANG, B.D. DEPAOLA, J. R. MacDonald Laboratory, Kansas State University, Manhattan, KS 66506 — A tremendous amount of work, both theoretical and experimental, has recently been invested in finding efficient coherent excitation techniques to control the population transfer between specified energy states. Measuring the population changes in real time and probing all levels involved during coherent excitation are some of the challenges that most experiments have had to face. Our experiment overcomes these difficulties by employing a modern diagnostic technique, known as Magneto-Optical Trap Recoil Ion Momentum Spectroscopy (MOTRIMS), which makes use of an ion beam as a non-intrusive probe of a three-level rubidium ladder system, coherently excited via the standard STIRAP (stimulated Raman adiabatic passage) method. Several cases are investigated, in which the temporal delay between the two laser pulses is varied, ranging from the so-called counter-intuitive order to the intuitive order. The population dynamics of all three levels involved in the STIRAP process is measured with a resolution of a few nanoseconds. Experimental results are compared with predictions of theory.

3:06PM Q4.00009 Zeeman Slower for Fermionic Potassium Atoms with Natural Abundance Sample , YE-RYOUNG LEE, PETER ZARTH, Massachusetts Institute of Technology, MARTIN WEITZ, University of Tübingen, WOLFGANG KETTERLE, Massachusetts Institute of Technology — We present a new atomic source for \(^{40}\text{K} \) based on a Zeeman slower using natural abundance potassium. This method has practical and technical advantages over the conventional method of using enriched potassium. At the position of the \(^{40}\text{K} \) MOT, the Zeeman slower has a maximum flux of \( 2 \cdot 10^7 \text{ atoms/s/cm}^2 \), which is comparable to other techniques. This new atomic source saves expenses by not using enriched \(^{40}\text{K} \) samples and simplifies complications in other techniques. Our method serves as a simple and robust \(^{40}\text{K} \) source for the studies of fermionic atoms.

3:18PM Q4.00010 Design and performance of an optimized dual-species Zeeman slower . RYAN OLFE, G. EDWARD MARTI, DAN STAMPER-KURN, Department of Physics, University of California, Berkeley — An increasing number of experiments cool and trap multiple atomic species both simultaneously and alternatively. We present a Zeeman slower optimized for dual species operation via precise rending of multiple sections targeted at the individual species, with only marginally reduced performance than a slower designed for each species individually. The currently constructed slower is optimized for Li and Rb atoms emerging from a dual-species oven and eventually captured by a MOT, though other atomic mixtures are discussed. Design, construction, and performance results and considerations are shown.

3:30PM Q4.00011 Velocity-selective two-photon resonances in a cold atomic sample with large one-photon blue detunings , MATTHEW TERRACIANO, SPENCER OLSON, MARK BASHKANSKY, ZACHARY DUTTON, FREDRIK FATEMI, Naval Research Laboratory — We present experimental results on velocity-selective, magnetically-induced resonances in a cold Rb vapor. For small detuning from the D2 transition (\( |\Delta| < 50 \text{ MHz} \)), we observe cooling only for negative \( \Delta \) as expected, but at larger detuning (\( |\Delta| \geq 0.1-10 \text{ GHz} \)) we find evidence for cooling with both blue- and red-detuning. To observe this effect, a freely expanding atomic cloud is cooled to \( \sim 10^{-10} \text{ ms pulse from lin-perp lin counterpropagating fields. The expanding cloud is later imaged and shows higher density for a narrow velocity class of atoms that is resonant with a two-photon transition whose Doppler shift corresponds to the Larmor precession frequency. We use this effect to demonstrate a simple technique for measuring (or zeroing) the magnetic field to within 1 mG, as verified by Faraday rotation. Furthermore, we cool several velocity classes simultaneously by imposing multiple frequency sidebands on one beam of the counterpropagating pair, and extend the experiments to two dimensions.

3:42PM Q4.00012 Subnatural linewidth spectroscopy using a suppression and recovery of trapped Cs atoms , CHIN-CHUN TSAI, RAY-YUAN CHANG, MIN-DA TSAI, WEI-CHIA FANG, YI-CHIH LEE, Department of Physics, National Cheng-Kung University, Tainan, Taiwan — Subnatural linewidth in the 8s Rydberg state has been observed using a suppression and recovery of trapped Cs atoms. The suppression and recovery method has the advantages of requiring low light field for probing laser and providing a zero background. In our experiment, the Cs atoms in the magneto-optical trap (MOT) are radiated by a weak probe laser field \(|6S_{1/2} F=4\rangle \rightarrow |6P_{3/2} F=5\rangle \text{ for } 1000\text{ms}; \text{ then a coupling laser is superimposed with the probing laser to interact with the MOT atoms for 500\text{ms by alternating the MOT lasers with the coupling laser at 70kHz to avoid the power broadening and the AC stark effect. The coupling laser is scanned from } |6P_{3/2} F=5\rangle \rightarrow |8S_{1/2} F=4\rangle. \text{ If the coupling laser is off resonance, then the probe laser suppresses the atoms to be loaded into the MOT and results no background signal while probing the MOT florescence. If the coupling laser is on resonance, then the probe laser is induced to be transmitted and the MOT loading is recovered at the alternating stage. This transmitted probe laser field is due to quantum interference and is known as the electromagnetically induced transparency. A subnatural linewidth in the Cs(8s) Rydberg state of 3.5MHz is obtained and the intensity dependence on the probing coupling lasers is discussed.}

Friday, June 8, 2007 1:30PM - 3:54PM
Session Q5 Quantum Cryptography and Communication
TELU Convention Centre Macleod A3-A4
1:30PM Q5.00001 Experimental techniques to enhance the performance of quantum key distribution systems. YI ZHAO, BING QI, XIONGFENG MA, HOI-KWONG LO, CQIQC, Dept. of Physics and Dept. of ECE, University of Toronto — Practical quantum key distribution (QKD) system has many imperfections, causing several security concerns. Nonetheless, people have proven the security of imperfect practical QKD systems. There are several approaches to enhance the performance of practical QKD system. A famous one is the decoy method, which can dramatically improve the efficiency of QKD (i.e., higher key rate, longer transmission distance) without jeopardizing the security. Another one is the phase randomization, which can improve the security of the QKD system (by making it closer to theoretical assumptions) without reducing the efficiency. Here, we report the first experimental implementations of the decoy method and the active phase randomization. We implemented two decoy state QKD protocols: the one-decoy protocol over 15km telecom fiber, and the weak+vacuum protocol over 80km telecom fiber. We also implemented the active phase randomization and that the efficiency of the QKD system was not reduced.


1:42PM Q5.00002 Quantum key distribution with entangled sources. XIONGFENG MA, CHI-HANG FRED FUNG, HOI-KWONG LO, University of Toronto — We propose a model and a post-processing protocol for quantum key distribution (QKD) with entangled photons from a parametric down-conversion (PDC) source. We also investigate the entanglement PDC QKD with two-way classical communications. We find that the recurrence scheme increases the key rate and Gottesman-Lo protocol helps tolerate higher channel losses. By simulating a real QKD setup, we compare three implementations — entanglement PDC QKD, triggering PDC QKD and coherent state QKD. The simulation result suggests that the entanglement PDC QKD can tolerate higher channel losses than the coherent state QKD. On the other hand, the coherent state QKD with decoy states is able to achieve highest key rate in the low and medium-loss regime. By applying Gottesman-Lo two-way post-processing protocol, the entanglement PDC QKD can tolerate up to 70dB combined channel losses (35dB per each channel) provided that the PDC source is placed in between Alice and Bob rather than at Alice’s side. Since a 35dB channel loss is similar to the estimated loss in a satellite to ground quantum transmission, our result is in agreement with the suggestion in the literature that secure QKD between two ground locations via an untrusted satellite with an entanglement-based PDC source appears to be technologically feasible.

1:54PM Q5.00003 Eavesdropping of quantum communication from a non-inertial frame. KAMIL BRADLER, Institute of Physics, UNAM — We introduce a relativistic version of quantum encryption protocol by considering two inertial observers who wish to securely transmit quantum information encoded in a free scalar quantum field state forming Minkowski particles. In a non-relativistic setting a certain amount of shared classical resources is necessary to perfectly encrypt the state. We show that in the case of a uniformly accelerated eavesdropper the communicating parties need to share (asymptotically in the limit of infinite acceleration) just half of the classical resources.

2:06PM Q5.00004 Towards Hybrid Quantum Communication Networks. WOLFGANG TITTEL, University of California, Canada, OLIVIER ALIBART, PASCAL BALDI, University of Nice, France, NICOLAS GISIN, MATTHAEUS HALDER, University of Geneva, Switzerland, IVAN MARCICKI, National University of Singapore, Singapore, HUGUES DE RIEDMATTEN, University of Geneva, Switzerland, SEBASTIEN TANZILLI, University of Nice, France, HUGO ZBINDEN, University of Geneva, Switzerland — The last years have seen a remarkable advance of applications of quantum communication. The most important example is quantum cryptography that is now at the verge of becoming an industrial application. One of the future challenges to make this technology widely available is the integration of point-to-point links into networks that may consist of hybrid quantum communication channels with fibre optic and free-space links. I will report on experiments that allow transferring quantum information between photons at different wavelengths, as required for different quantum channels, either based on quantum teleportation [1], or on parametric up-conversion in a non-linear crystal [2]. [1] I. Marcikic, H. de Riedmatten, W. Tittel, H. Zbinden, N. Gisin, Nature 421, 509 (2003). [2] S. Tanzilli, W. Tittel, M. Halder, O. Alibart, P. Baldi, N. Gisin, H. Zbinden, Nature 437, 116 (2005).


2:30PM Q5.00006 Hybrid Entanglement for Optical Quantum Networks. FELIX BUSSIERES, NICOLAS GODBOUT, Ecole Polytechnique de Montreal, WOLFGANG TITTEL, University of Calgary — A global optical quantum communication network will have to operate with different encodings of quantum information (QI) depending on the medium in which the photons are carried. Polarization qubits in the visible spectrum are well suited for free-space transmission due to the absence of birefringence in the air, whereas time-bin qubits at telecom wavelengths are more suited for optical fiber transmission due to their resistance to polarization mode dispersion. We present a scheme to generate hybrid photonic entanglement defined as entanglement between different encodings of QI using light. In this specific case we consider a time-bin photon at 1550 nm entangled with a polarization photon at 1270 nm. We also show how to teleport a polarization qubit to a time-bin qubit using this type of entanglement. Finally, we discuss how this allows QI to be distributed over optical quantum networks interfacing free-space and optical fiber links hence increasing the versatility of such networks.

3:06PM Q5.00009 Remote Preparation of an Atomic Quantum Memory, M. WEBER, W. ROSENFELD, J. VOLZ, S. BERNER, Department of Physics, LMU Munich, Germany, H. WEINFURTER, Department of Physics, LMU Munich and Max-Planck Institute of Quantum Optics, Garching, Germany — Storage and distribution of quantum information are key elements of quantum information processing and quantum communication. Here, using atom-photon entanglement as the main physical resource [1], we experimentally demonstrate the preparation of a distant atomic quantum memory. Applying a quantum teleportation protocol on a locally prepared state of a photonic qubit, we realized this so-called remote state preparation on a single, optically trapped Rb87 atom. We evaluated the performance of this scheme by the full tomography of the prepared atomic state, reaching an average fidelity of 0.82 [2]. The principles enabling the successful remote state preparation now also can be applied to further quantum communication protocols, e.g. the quantum teleportation from light to matter and last but not least the quantum repeater [3].


3:18PM Q5.00010 Dual Species Matter Qubit Entangled with Light, S.-Y. LAN, S.D. JENKINS, T. CHANDELIERE, D.N. MATSÜKEVICH, C.J. CAMPBELL, R. ZHAO, T.A.B. KENNEDY, A. KUZMICH, Georgia Institute of Technology — We propose and demonstrate an atomic qubit based on a cold 87Rb-85Rb isotopic mixture, entangled with a frequency-encoded optical qubit. The interface of an atomic qubit with a single spatial light mode, and the ability to independently address the two atomic qubit states, should provide the basic element of an interferometrically robust quantum network.

3:30PM Q5.00011 Quantum interference of two photons emitted by two trapped Yb ions, KELLY C. YOUNGE, DAVID L. MOEHRING, STEVEN OLMSCHENK, DMITRY MATSÜKEVICH, PETER MAUNZ, MARTIN J. MAIDEN, LUMING DUAN, CHRIS MONROE, FOCUS Center and Department of Physics, University of Michigan — Distant, entangled qubits represent a universal resource for quantum communication protocols and distributed quantum computing. One method to entangle two distant particles involves detecting a single photon from each particle after the photons have interfered. We demonstrate this two-photon quantum interference by using an ultrafast laser to excite two ytterbium ions trapped in spatially separated rf Paul traps. The emitted photons are transmitted through optical fibers to achieve high, stable mode overlap on a beam splitter. Two-photon interference, along with the excellent state preparation and detection available in trapped ion systems, should allow the two ions to be entangled without involving their motion. Such a quantum link can be used as a fundamental resource for large-scale quantum networks and scalable quantum computers.

This work is supported by the U. S. National Security Agency and the Disruptive Technology Office under Army Research Office contract, and the National Science Foundation ITR and PIF programs.

Friday, June 8, 2007 1:30PM - 3:30PM — Session Q6 Quantum States of Light TELUS Convention Centre Olde Scotch Room

1:30PM Q6.00001 Deterministic Single Photons via Conditional Quantum Evolution, C.J. CAMPBELL, D.N. MATSÜKEVICH, T. CHANDELIERE, S.D. JENKINS, S.-Y. LAN, T.A.B. KENNEDY, A. KUZMICH, Georgia Institute of Technology — A source of deterministic single photons is proposed and demonstrated by the application of a measurement-based feedback protocol to a heralded single-photon source consisting of an ensemble of cold rubidium atoms. Our source is stationary and produces a photoelectric detection record with sub-Poissonian statistics.

1:42PM Q6.00002 Polarization Squeezing in Atomic Rubidium Vapour, GEOFF CAMPBELL, CHRIS HEALEY, JURGEN APPEL, KARL-PETER MARZLIN, ALEX LVOVSKY, Institute for Quantum Information Science — Recently there has been debate regarding the possibility of using polarization self-rotation (PSR) in a thermal vapour cell as a mechanism for generating a squeezed vacuum state [1]. It has been claimed that the squeezing produced by this method is overwhelmed by atomic noise in the thermal vapour [2]. We present a new experimental study on the possibility to generate squeezing in this system and theoretical results that highlight the importance of the atomic ground state decoherence.


1:54PM Q6.00003 A General Linear-Optical Quantum State Generator, DMITRY USKOV, Tulane University, NICKOLAS VANMETER, PAVEL LOUGOVSKI, JONATHAN DOWLING, Louisiana State University — We introduce a notion of a linear-optical quantum state generator. This is a device that prepares a desired quantum state using product inputs from photon sources, linear-optical networks, and post-selection using photon counters. We show that this device can be concisely described in terms of polynomial equations and unitary constraints. We illustrate the power of this language by applying the Groebner-basis technique along with the notion of vacuum extensions to solve the problem of how to construct a quantum state generator analytically for any desired state, and use methods of convex optimization to identify success probabilities. In particular, we disprove a conjecture concerning the preparation of the maximally path-entangled NOON-state by providing a counterexample using these methods, and we derive a new upper bound on the resources required for NOON-state generation.

This work is funded by the Army Research Office and the DisruptiveTechnologies Office.
2:06PM Q6.00004 Semiconductor Waveguides for Correlated Photon Generation, DANIEL ROGERS, University of Maryland Chemical Physics Program, JOSHUA BIENFANG, National Institute of Standards and Technology. JULIUS GOLDHAR, Department of Electrical and Computer Engineering, University of Maryland, CHRISTOPHER RICHARDSON, Laboratory for Physical Science, University of Maryland, CHARLES CLARK, National Institute of Standards and Technology — The next generation of quantum cryptography will benefit from a fast and practical source of entangled photon pairs. Current methods of generating entangled photon pairs, whether in nonlinear crystals or exotic microstructure optical fibers, pose significant challenges to integration into fieldable quantum communications systems. In order to meet the demands of speed and practicality, nonlinearities in semiconductor waveguides are being investigated as sources of correlated and ultimately entangled photons. These devices offer the advantages of having a fast nonlinear response and being able to couple to standard optical fibers. We investigate the feasibility of using a bulk AlGaAs waveguide and birefringent phase matching to generate correlated photon pairs compatible with silicon detectors. This source is potentially useful for free-space and fiber-optic quantum key distribution, as well many other applications such as correlated photon metrology and squeezing experiments. We consider the effects of loss and two-photon absorption and show that birefringent phase matching has significant advantages over tailored group velocity dispersion in filtering and Raman noise suppression.

2:18PM Q6.00005 Optical entanglement by frequency upconversion, MARK SAFFMAN, University of Wisconsin Madison, O-O-KAW LIM, University of Wisconsin - Madison — We demonstrate theoretically and experimentally that continuous variable entangled light beams can be created by frequency upconversion. The experiment uses a cavity which has two output ports for the second harmonic. The two output beams share a common pump beam which serves to create correlations between the beams. We demonstrate the presence of these correlations by showing that the measured non-classical intensity correlation is larger than the amplitude squeezing of each beam. We also demonstrate experimentally that the beams are inseparable according to the criterion of Duan, Giedcke, Cirac, and Zoller. We expect that this new approach to entanglement generation may be useful for experiments in quantum enhanced lithography.

2:30PM Q6.00006 Electronic Noise in Optical homodyne Tomography, DALLAS HOFFMAN, JURGEN APPEL, EDEN FIGUEROA, ALEX LVOVSKY, IQIS U of C, IQIS U OF TEAM — In experiments on homodyne tomography of light, the electronic noise of the detector often prevents the observation of the fine details of the quantum state’s marginal distributions. We have shown that the noise contribution from the detector can be modeled by an equivalent inefficiency arising due to optical loss. We confirm this result using a non-classical squeezed light produced with an optical parametric amplifier.

2:42PM Q6.00007 Quantum states for Heisenberg limited interferometry, HERMANN UYS, PIERRE MEYSTRE, Department of Physics, University of Arizona — An important aspect of quantum metrology is the engineering of quantum states with which to achieve Heisenberg limited measurement precision. In this limit the measurement uncertainty is inversely proportional to the number of interfering particles, N, a 1/√N improvement over the standard quantum limit. We have used numerical global optimization strategies to systematically search for quantum interferometer input states that achieve Heisenberg limited uncertainty in estimates of the interferometer phase shift. We compare the performance of candidates so obtained with that of non-classical states already known to yield Heisenberg limited uncertainty.

2:54PM Q6.00008 Multipartite squeezed states as SU(1, 1) coherent states, ZAHRA SHATERZADEH YAZDI, PETER S. TURNER, BARRY C. SANDERS, University of Calgary — One goal of quantum information science is quantum information processing using complex quantum optical networks comprising passive and active linear optical elements, such as beam splitters and squeezers. Such a network can be described mathematically as a Sp(2n, R) transformation on n modes, which corresponds to mappings that preserve Gaussian states. Recently tripartite squeezed states have been produced experimentally and are quite useful for quantum information tasks such as quantum state sharing and quantum teleportation. We have developed a theoretical framework for three-boson realizations of SU(1, 1) and characterized all squeezed states of this type as SU(1, 1) coherent states. Inspired by the elegance of this theory, we generalize it to multi-boson realizations of SU(1, 1) that characterize any multiport linear optical system constructed from a two-mode squeezed and several passive elements, or by concatenating such multiport systems to each other. Thus, this theory gives us new insight into the properties of multipartite squeezed states generated in any complex optical network with concatenated sections each with one two-mode squeezed.

3:06PM Q6.00009 Quantum analysis of a Nonlinear Beam splitter: third-order nonlinearity, HARI PRAKASH, Physics Department, University of Allahabad, Allahabad-211002, India, DEVENDRA KUMAR MISHRA, Physics Department, University of Allahabad, Allahabad-211002, India and V. S. Mehta College of Science, Bharwari, Kaushambi-212201, India — A linear beam splitter mixes two input modes having annihilation operators, say, ˆa and ˆb, to generate two output modes having annihilation operators, say, ˆc and ˆd. It is common to write ˆc = ˆa + i ˆb, ˆd = ˆb + i ˆa, where the real constants t and r denote coefficients of transmission and reflection, respectively, and t^2 + r^2 = 1. We generalize the linear beam splitter input-output relations to include third-order nonlinearity and show that the nonlinear terms can give non-classical outputs with classical inputs. We study generation of squeezing and sub-Poissonian statistics for coherent light inputs.

3:18PM Q6.00010 Detecting hidden differences via permutation symmetries, PETER TURNER, Institute for Quantum Information Science, University of Calgary, ROB ADAMSON, Department of Physics, University of Toronto, MORGAN MITCHELL, Institut de Ciencies Fotoniques, Barcelona, AEPHRAIM STEINBERG, Department of Physics, University of Toronto — We present a method for describing and characterizing the state of N experimentally indistinguishable particles, that is to say particles that cannot be individually addressed due to experimental limitations. The technique relies upon a correct treatment of the exchange symmetry of the state among experimentally accessible and experimentally inaccessible degrees of freedom. Our technique is of direct relevance to ongoing experiments in quantum optics, for which we provide a specific implementation.
Controlled vibrational quenching of nuclear wave packets in $D_2^+$, THOMAS NIEDERHAUSEN, UWE THUMM, James R. Macdonald Laboratory, Kansas State University — The sudden ionization of neutral $D_2$ molecules by a short and intense pump laser pulse may create a wave packet as a coherent superposition of vibrational states on the lowest ($1\sigma_g^+$) adiabatic potential curve of the $D_2^+$ molecular ion. We investigate the possibility of manipulating the bound motion, dissociation, and vibrational-state composition of such nuclear wave packets with one (or several) ultra-short (6 fs) intense ($1 \times 10^{14}$ W/cm$^2$) near infrared (800 nm) control laser pulses. We show numerically that a single control pulse with an appropriately tuned time delay can significantly quench the vibrational state distribution of the nuclear wave packet by increasing the contribution of a selected vibrational state of the molecular ion to more than 50%. We also show that a second control pulse with a carefully adjusted delay can further squeeze the vibrational state distribution and suggest a scheme for a multi control pulse “Raman shaping”. Since the resulting nuclear wave function is almost stationary, fragmentation of the molecular ion with a final intense probe pulse can be used to project its nodal structure onto the measurable kinetic energy release, thereby suggesting a tool for assessing the degree at which the nuclear motion in a small molecule can be controlled.

This work is supported by the NSF and US DoE.

R1.00003 Engineering Rydberg Wavepackets Using a Chirped Half-Cycle Pulse Train1, JEFFREY MESTAYER, WEI ZHAO, JIM LANCASTER, F. BARRY DUNNING, Department of Physics and Astronomy, Rice University, SHUHEI YOSHIDA, Vienna University of Technology, CARLOS REINHOLD, Oak Ridge National Laboratory, JOACHIM BURGDORFER, Vienna University of Technology — A protocol for driving Rydberg atoms to a narrow band of targeted final states with the aid of a chirped train of half-cycle pulses (HCPs) is described. A localized wavepacket can be generated and maintained by a periodic driving force. The dynamics of such a wavepacket can be manipulated almost as easily and as freely as the dynamics of a single classical particle. This is demonstrated experimentally by exciting potassium atoms to the lowest-lying quasi-one-dimensional (quasi-1D) states in the $n = 350$ Stark manifold and transporting them to a narrow range ($\Delta n \sim \pm 20$) of higher-$n$ states centered on values of $n$ of up to $n \sim 670$. The protocol is remarkably efficient, with over 90% of the parent atoms surviving the HCP sequence in strongly-polarized quasi-1D states.

1Research supported by the DOE, the NSF, the FWF (Austria), and the Robert A. Welch Foundation.

R1.00004 Rovibrational wave packet manipulation using shaped mid infrared femtosecond pulses toward quantum computing, MASAAKI TSUBOUCHI, TAKAMASA MOMOSE, The University of British Columbia — Laser pulse shaping which was developed in near infrared (NIR) has been recently extended into mid infrared (MIR: 3 – 10 µm). In the presented study, the signal output (NIR: 1.1 – 1.5 µm) of an optical parametric amplifier was shaped with a Dazzler, and mixed in an AgGaS$_2$ crystal with the idler pulse to generate MIR pulses. Although the relation between the shapes of NIR and MIR light is complicated due to DFG process in the crystal with finite (2 mm) thickness, the shape of MIR light can be completely characterized by comparing with calculated profiles. The shaped MIR light which is well characterized can be used to manipulate rovibrational wave packet on the electronic ground state. We simulated the wave packet motion and its observable by solving the time-dependent Schrödinger equation, and discussed how the shape of MIR pulse is transferred into the wave packet. Application of rovibrational wave packet manipulation to quantum computation will be discussed.

R1.00005 Population transfer in Na s-p Rydberg ladder by chirped microwave pulse, H. MAEDA, J.H. GURIAN, T.F. GALLAGHER, Department of Physics, University of Virginia, Charlottesville, VA 22904, USA — Quantum defects of $n$s and $n$p Rydberg states of Na are quite large, $\delta_s = 1.35$ and $\delta_p = 0.85$, respectively, while for $n\ell$ states with $\ell \geq 2$ values of $\delta_\ell$ are nearly zero. Therefore Na $n$s and $n$p states are energetically isolated from the higher angular-momentum states in the same $n$ manifold. Together with the fact that energy spacing between $n$s and $n$p states and $n$s and $(n-1)p$ states are almost equal, i.e., $\Delta E_{n s-np} \approx \Delta E_{(n-1)p-n s} \approx 1/2n^3$ in a.u., we can think of Na $n$s and $n$p Rydberg states as a specific example of simple ladder system consisting with only $s$ and $p$ angular momentum states. Here we demonstrate that population transfer in the Na s-p Rydberg ladder can be effectively achieved using a frequency chirped microwave pulse, which dominantly couples only $s$ and $p$ states under a suitable condition. This work has been supported by the NSF.

Quantum Control of Atomic Hydrogen Using Laser Fields1, XINGJUN ZHANG, EDDIE RED, ALBERT WYNN III, CHARLES WEATHERFORD, Florida A&M University — A method for the ab initio simulation of STIRAP (stimulated Raman adiabatic passage) [1,2] laser quantum control of the energy level populations of atomic ions will be described. The method employs a new algorithm for the solution of the time-dependent Schrödinger equation which avoids the time-propagator and uses spectral elements in time with spectral nodal approximations. Together with the fact that energy spacing between $n$s and $n$p states and $n$s and $(n-1)p$ states are almost equal, i.e., $\Delta E_{n s-np} \approx \Delta E_{(n-1)p-n s} \approx 1/2n^3$ in a.u., we can think of Na $n$s and $n$p Rydberg states as a specific example of simple ladder system consisting with only $s$ and $p$ angular momentum states. Here we demonstrate that population transfer in the Na s-p Rydberg ladder can be effectively achieved using a frequency chirped microwave pulse, which dominantly couples only $s$ and $p$ states under a suitable condition. This work has been supported by the NSF.

Present address: Precision Photonics, Boulder, CO.

1Supported by the FAMU-NSF-CREST Center for Astrophysical Science and Technology and by the U.S. Army SSRID Program.
R1.00010 Coherence in a strongly driven four-level molecular system, JIANBING QI, Penn State University at Berks — We will present a detailed discussion of the coherence effect of a four-level molecular system driven by three lasers. A weak probe laser is used to probe a ground state to the first excited state. The response of the probe laser depends on the relative coupling strength of the two coupling lasers. The population spectra of the excited states display complex structures which are strongly affected by the driving lasers and detuning of the lasers. We used density matrix equations to derive analytical solutions for the probe absorption and the population spectra. We will also discuss the control of the population of the excited states by the coupling lasers.

R1.00011 Effects of coupling between the vibrational modes on CARS signal, VISHESH PATEL, SVETLANA MALINOVSKAYA, Stevens Institute of technology — CARS is well suited spectroscopy method for imaging specific molecules, e.g., proteins and live cells, diagnosis of cancerous cells, imaging deuterated compounds, etc. CARS imaging techniques avoid problems associated with photo bleaching and photo induced toxicity. The CARS signal is accompanied by a strong non resonant background which may overshadow the weak signal of interest. Two methods, using femtosecond chirped laser pulses and providing the Rabi oscillation and the adiabatic passage type of control [1], allow one to achieve sensitivity with high resolution and are known to efficiently suppress background. It has been previously shown that coupling between vibrational modes affects the sensitivity of the Raman signal and selective excitation of vibrational modes [2]. In this paper we will discuss results on vibrational coupling between modes and its impact into control mechanisms of the CARS signal.


R1.00012 Coherence in a strongly driven four-level molecular system, JIANBING QI, Penn State University at Berks — We will present a detailed discussion of the coherence effect of a four-level molecular system driven by three lasers. A weak probe laser is used to probe a ground state to the first excited state. The response of the probe laser depends on the relative coupling strength of the two coupling lasers. The population spectra of the excited states display complex structures which are strongly affected by the driving lasers and detuning of the lasers. We used density matrix equations to derive analytical solutions for the probe absorption and the population spectra. We will also discuss the control of the population of the excited states by the coupling lasers.

R1.00013 Generation of High-Power Laser Light with GHz Splitting, NICK PROITE, BRETT UNKS, DENIZ YAVUZ, University of Wisconsin - Madison — We demonstrate the generation of two high-power laser beams whose frequencies are separated by the hyperfine transition frequency in Rb-85. The system uses a single master diode laser appropriately shifted by a high frequency acousto-optic modulator and amplified by tapered amplifiers. This system produces two 1 Watt laser beams with a frequency spacing of 3.035 GHz. We discuss possible applications of this system including Electromagnetically Induced Transparency-like effects in both hot vapor cells and ultracold atomic clouds.

R1.00014 The N+CPT resonance, MICHAEL CRESCIMANNO, Department of Physics and Astronomy, MICHAEL HOHENSEE, CINDY HANCOX, DAVID PHILLIPS, RON WALSWORTH, Harvard-Smithsonian Center for Astrophysics — Of relevance to compact atomic frequency standards, we investigate a model of the N+CPT joint optical resonance. We compare analytical solutions of a 4-state theory, as well as numerical solutions of the optical Bloch equations, to experimental investigations of N+CPT resonances in 87Rb. Our results inform the optimization of N+CPT based frequency standards.

3 Youngstown State University

R1.00015 ABSTRACT WITHDRAWN —

R1.00016 CAVITY QED —

R1.00017 Studies of many atoms strongly coupled to a high finesse optical cavity, KATER MURCH, UC Berkeley, KEVIN MOORE, SUBHADEEP GUPTA, DAN STAMPER-KURN — We utilize a hybrid magnetic trap – cavity QED apparatus to conduct studies of ultracold atoms strongly coupled to a high finesse optical cavity. Up to $5 \times 10^4$ $^{87}$Rb atoms are trapped at the antinodes of an in-cavity far-off resonance optical standing wave. Atoms can be either probed directly using absorption imaging, or indirectly from the shift of the cavity resonance. Using a combination of these probes, we conduct measurements of the heating in the system. For strongly coupled cavities, quantum-optical properties of the cavity system strongly influence the heating of the atomic sample. Cavity-induced heating dominates for single systems with large single-atom cooperativity, and may limit cavity-based quantum non-demolition measurements such as those being pursued experimentally by our group and others.

R1.00018 Barium ion trap cavity QED, ADAM STEELE, LAYNE CHURCHILL, PAUL GRIFFIN, MICHAEL CHAPMAN, Georgia Institute of Technology — We have constructed a barium ion trap cavity QED system that is designed to reach the strong coupling regime. Strong coupling between a single atom and an optical cavity is an important paradigm for quantum optics and an important element for quantum information processing. We have confined laser cooled chains of barium ions in a linear Paul trap. These ions will be coupled to a mode in a high finesse optical cavity resonant with the $5\textsc{s}_{1/2} \rightarrow F_{1/2}$ transition at 493 nm. We present our progress towards this integration of ion trap and cavity QED technologies.

R1.00019 Steady state of two-mode cavity QED beyond the low intensity, REBECCA OLSON KNELL, DAVID NORRIS, JIETAI JING, LUIS A. OROZCO, QJI-University of Maryland — Cavity QED with two orthogonal polarization modes with multilevel atoms permits the identification of spontaneous emission through the light escaping in the undriven mode. We present our experimental investigations of the steady state behavior of this system when the resonant drive of one of the cavity modes is strong. This driving regime also has entanglement that does not suffer from the intrinsic problem of a large vacuum component for the low intensity cavity QED. Our apparatus includes laser cooled Rb atoms that traverse a high finesse optical cavity. The coupling rate of the cavity mode to the atom $g$, the cavity decay rate $\kappa$, and the atomic fluorescence rate $\gamma$ are all similar and much larger than the inverse of the single atom transit time across the mode, so that multiple interactions between the light and the atom are possible. The parameters of the experiment place it in the intermediate regime of cavity QED states. We look at the transmitted light out of the cavity in the two orthogonal modes. We compare our results to a model that includes three levels, two ground states and one excited state as a function of number of atoms and drive intensity.

1. Work supported by NSF

R1.00020 Evaporative Cooling of a Photon Fluid, BRIAN SEAMAN, DOUGLAS MASON, MURRAY HOLLAND, JILA and Department of Physics, CU Boulder — The field of ultracold atomic physics has made large advances using the insight gained from the manipulation of optical fields. We explore the opposite, recreating in optical systems effects usually seen only in atomic systems. The possibility of evaporatively cooling a “photon fluid” in a Fabry-Perot cavity is considered. This would allow for the creation a superfluid coherent beam of light from an incoherent source without inversion.

R1.00021 ULTRACOLD MATTER III —
**R1.00022** Optical bottle beams for trapping neutral atoms, LARRY ISENHOWER, MARK SAFFMAN, University of Wisconsin — We describe a novel interferometric approach to implementing a bottle beam which can be used for trapping of atomic species in regions of low intensity. Using a Mach-Zehnder interferometer with unequal magnification in the two arms we demonstrate an optical field which has low intensity surrounded by bright regions in all directions. The bottle beam provides a quartic trapping potential transverse to the symmetry axis of the trap, and is a possible route to tight confinement of single atoms in three spatial dimensions using optical access from a single side of the experiment. We discuss the decoherence properties of this type of trap for holding neutral atom qubits, and show that it in principle can be used to create an attractive potential simultaneously for both ground state and Rydberg atoms.

1Supported by the NSF and ARO-DTO.

**R1.00023** Portable Atom Chip Vacuum Cell for Rapid BEC Production, MATTHEW B. SQUIRES, EVAN A. SALIM, WILLIAM F. HOLMGREN, DANA Z. ANDERSON, Department of Physics and JILA, University of Colorado at Boulder, STERLING E. MCBRIDE, STEVEN A. LIPP, Sarnoff Corporation, JEFFERY F. DENATALE, ROBERT E. MIHAIVOLICH, Teledyne Scientific and Imaging, LLC — We have developed a portable BEC system capable of fast loading of atoms onto an atom chip using a double MOT arrangement to spatially separate a high vapor pressure atom source region from an atomic cooling and chip region. The atom chip serves as one wall of the vacuum cell and has through-wafer optical electric and via connections, which simplifies connection to on-chip conductors. The cell is constructed using an epoxy-less technique, which permits high bake-out temperature. We have observed that high bake out temperatures leads to excellent vacuum properties, but eliminates the effectiveness of light-assisted atom desorption as a means to modulate rubidium vapor pressure. Instead, fast loading in a 6 beam MOT is obtained by loading from a 2D MOT in a separate high vapor pressure region isolated from the UHV section with a 1 mm aperture. Captured atom flux is as high as $10^6$ atoms/sec in the 6-beam MOT.

1Supported by DARPA DSO and NSF.

**R1.00024** Cost-effective magneto-optical trap of ytterbium atoms, CHANG YONG PARK, WON-KYU LEE, DAI-HYUK YU, HO SUHNG SUH, SANG EON PARK, EOK BONG KIM, Korea Research Institute of Standards and Science, QUANTUM APPLICATION SI LAB. TEAM — We report on a cost-effective magneto-optical trap (MOT) of ytterbium atoms by using diode lasers as a previous step for a normal optical lattice clock. For the purpose of MOT, we have newly designed GaN external cavity laser diodes (ECLD), which outputs 10 mW at a wavelength of 399 nm. One of the ECLD is used to trap the ytterbium atoms along x-axis, while additional F-P diode lasers, which is injection locked to the previous ECLD, is used for the trapping along y and z axes. These trapping lasers are frequency stabilized to Doppler free $1^2S_0^-1^2P_1$ transition. We have trapped $5 \times 10^6$ atoms for $^{174}Yb$ and $2 \times 10^6$ atoms for $^{177}Yb$ respectively at a trapping temperature of 1 mK, which is still too high for settling the atoms inside the optical lattice. In order to further decrease the trapping temperature an additional cooling laser is necessary corresponding to $1^2S_0^-1^2P_1$ transition with which ytterbium atoms can be cooled to 4 K.

To obtain the desired laser, 1112 nm ECLD with 200 mW output is frequency doubled through MgO doped PPLN waveguide.

**R1.00025** Rotating-radio-frequency ion traps, T. HASEGAWA, Dept. Phys., Keio Univ., Kanagawa 223-8522, Japan, J.J. BOLLINGER, NIST, Boulder, CO 80305 — We discuss a new ion trap, the rotating-radio-frequency (rotating-rf) trap, in which the motion of a charged particle is described by trigonometric functions rather than the usual Mathieu functions of a normal rf trap. In the rotating-rf trap, a rotating quadrupole electric field confines an ion, which is in a rotating rf trap, to a lattice of two non-degenerate circular secular motions and two corresponding circular micromotions. The cases of applying a uniform dc magnetic field and a quadrupole dc electric field in addition to the rotating rf field are also discussed. Confinement in a rotating-rf trap can be tighter than in a normal linear rf trap with the same experimental parameter values.


**R1.00026** Measurement of the KRb ground-state dissociation energy using cw depletion of ultracold molecules, DAJUN WANG, JIN-TAE KIM, EDWARD E. EYLER, PHILLIP L. GOULD, WILLIAM C. STWALLEY, Physics Department, University of Connecticut, Storrs, CT 06269 — We have combined previous spectroscopic data [1] on the $X^1\Sigma^+_2$ state of KRb with our recent binding energy measurements of high vibrational levels to obtain an improved value of the dissociation energy. Our measurement is carried out with ultracold KRb molecules formed by spontaneous emission following photoassociation of ultracold atoms. Pulsed laser ionization detection with vibrational selectivity and cw laser ion depletion with rotational resolution are used to measure the binding energies of high-$v''$ molecules directly. Using a common vibrational level, the term energy given in [1] is combined with our binding energy measurement to yield the dissociation energy of the $X^1\Sigma^+ 1^2$ state: $D_e = 4217.822 \pm 0.003$ cm$^{-1}$. We acknowledge support from NSF.


1Permanent Address: Chosun University, Department of Photonic Engineering, Gwangju, Korea

**R1.00027** Exploring Ultracold Atoms in Non-Abelian Gauge Potentials, J.Y. VAISHNAV, National Institute of Standards and Technology, I.I. SATIJA, National Institute of Standards and Technology and George Mason University, C.W. CLARK, National Institute of Standards and Technology — The motion of ultracold, multilevel atoms in spatially varying laser fields can generate non-Abelian gauge potentials, if two or more of the dressed states are degenerate. We examine the spectral and other exotic characteristics of ultracold atoms moving in such non-Abelian gauge potentials, with a view to understanding phenomena like symmetry breaking and non-Abelian Berry phase. Our work is motivated by numerous proposals to create non-Abelian gauge fields in cold atom experiments.

**R1.00028** Polarization-dependent neutral atom trapping potentials of 2D optical lattices on a chip, BERT DAVID COPSEY, KATHARINA GILLEN-CHRISTANDL, California Polytechnic State University, San Luis Obispo, RAJANI AYACHITULA, The Ohio State University — We present the results of our computational investigation of atom trapping potentials in different two-dimensional (2D) optical lattice geometries for neutral atoms in magnetic substates other than $m_F=0$. The geometries we test include the basic 2D optical lattice presented in [1], as well as variations of these lattices involving a counterpropagating beam pair along one dimension, and a lattice with variable trap spacing along one dimension. The 2D optical lattices are created by interference of the evanescent waves of two or more different modes in a slab waveguide. The main focus of our study is on identifying waveguide and trap light parameters that may allow for the implementation of 2-qubit gates using 2D optical lattices. 1. Phys. Rev. A 70 032302 (2004).
R1.00029 Adiabatic cooling of atoms trapped in a transformable optical trap, SEUNG KOO LEE, HUI DONG KIM, SIN HYUK YIM, D. CHO, Korea University — We demonstrate adiabatic cooling of rubidium atoms in an optical trap by gradually transforming the trap from a corrugated form of a standing wave to a flattened form of a traveling wave. We trap atoms in an optical trap formed by a Fabry-Perot interferometer, which is used as a power build up cavity (PBC). We phase modulate the trapping beam using an electro-optic modulator (EOM). When the modulation frequency is the same as a free spectral range of the PBC, both carrier and sidebands can couple to the cavity simultaneously. When the modulation index is 1.2, the carrier and the sidebands have the same power and the potential well near the center of the PBC becomes flat. By controlling the modulation index we can change time-averaged intensity distribution of the intra cavity trap beam from a standing wave to a flattened form of a traveling wave. Accompanying reduction in the oscillation frequency of the trapped atoms leads to adiabatic cooling for the longitudinal degree of freedom.

R1.00030 Observation of stationary and non-stationary flow past an obstacle in a Bose-Einstein condensate, PETER ENGELS, COLLIN ATHERTON, Washington State University, Pullman, WA 99164 — We experimentally study the fluid flow past an obstacle moving through an elongated Bose-Einstein condensate with repulsive interferences. Depending on the speed and strength of the obstacle, both stationary and non-stationary regimes are accessed. At slow speeds as well as at very fast speeds, stationary fluid flow is obtained. However, at intermediate speeds, a non-stationary regime is observed in which the condensate gets filled with a stack of dark solitons. Both attractive and repulsive obstacles are studied, and a significant difference in the critical velocities for nonstationary flow is found for the two cases.

R1.00031 Analytic Beyond-Mean-Field BEC Density Profiles at Next-Order in Dimensional Perturbation Theory, MARTIN DUNN, W. BLAKE LAING, DEBORAH WATSON, University of Oklahoma — The density profile of a BEC offers an experimentally accessible window into beyond-mean-field effects in a macroscopic quantum object. These effects include a greater spatial extent resulting from hard collisions within the system as well as fermionization and crystallization in quasi-one and two dimensional systems. Even at lowest order, dimensional perturbation theory (DPT) yields wave functions of large-N systems which include correlation effects, and which have previously been used to derive the lowest-order density profile. DPT has now been extended beyond the lowest order to the next-order wave function. In this work we show how to derive the next-order density profile (a function of one degree of freedom) from this next-order DPT wave function (a function of a very considerable number of degrees of freedom). The functional form of the higher-order density profile includes the possibility of fermionization/crystallization.

R1.00032 Interactions of low-energy ions and electrons with Bose-Einstein condensates, RACHEL SAPIRO, RUI ZHANG, GEORG RAITHEL, University of Michigan, FOCUS — We will present plans for experiments intended to explore interactions between low-energy ions and electrons and Bose-Einstein condensates (BECs). The BEC apparatus, which will be described in the presentation, is a double-trap system that employs miniature U-trap and Z-trap configurations for the final stages of atom trapping and cooling. Currently, we create BECs with \( N \) \( \geq 10^7 \) rubidium atoms. Planned modifications of the apparatus will allow us generate, control and image ions in present inside the BEC. In our presentation, we will describe the complete setup, discuss experimental progress, and outline the planned experiments. These include studies of changes in the effective mass of the ions due to clusters of atoms forming around them [1], and of perturbations of the BEC due to the presence of embedded ions [2].

R1.00033 Bose-Condensed \(^7\)Li in a Random Potential, JAMES HITCHCOCK, Y.P. CHEN, M. JUNKER, D. DRIES, C. WELFORD, R.G. HULET, Rice University Physics and Astronomy — Imposing a random potential on a Bose-Einstein condensate (BEC) of \(^7\)Li creates a unique system for studying superfluid behavior in the presence of disorder. We generate a random optical potential by passing a 1 mm laser through a ground glass, which creates intensity fluctuations in the beam that are then overlapped with the probe beam and propagated one the atoms. This setup allows for almost simultaneous imaging of the atomic cloud and the random potential. Parameters such as the disorder strength and disorder correlation length can be precisely characterized. We can control the disorder strength by varying the laser intensity and the atomic interaction (scattering length) via a Feshbach resonance. We have investigated the effects of disorder on dipole oscillation in a harmonic trap, and time of flight expansion of the BEC. This system has allowed us to study such phenomena as quantum phase fluctuations, localization and interplay between interaction and disorder.

R1.00034 First branch of liquid states of a many-atom Bose system, BO GAO, University of Toledo — We present more detailed properties of the first branch of the liquid states as suggested and studied recently, including the equilibrium density and the equilibrium energy-per-particle of the liquid, speed of phonons, and pair correlation functions. Results are presented both for liquid branches corresponding to negative scattering length and for those corresponding to positive scattering length.

R1.00035 Dilute Bose gases interacting via power-law potentials, RYAN KALAS, Department of Physics and Astronomy, Washington State University, and JILA, University of Colorado — Neutral atoms interact through van der Waals potentials, which asymptotically fall off as \( r^{-6} \). The behaviors of dilute Boses gases can to a good approximation be described by the atom-atom scattering length \( a_s \). However, as the system becomes more dense, corrections arise that depend on the characteristic length of the van der Waals potential. Making use of both essentially exact numerical calculations and semi-analytical solutions, we parameterize these corrections by analyzing the energetics of two- and few-atom systems under external harmonic confinement. We generalize these results to particles interacting through a longer-ranged potential, which asymptotically falls off as \( r^{-4} \). Finally, we consider homogeneous systems interacting through different power-law potentials.

1Supported by NSF, ONR, and the Welch and Keck Foundations.

2Supported by NSF.

3Supported by NSF.

4Supported by NSF.

5Supported by NSF.
**R1.00036 Effects of perturbations in photoassociation spectra of ultracold Cs$_2$**

MARIN PICHLER, Goucher College, Baltimore MD 21204, WILLIAM C. STWALLEY, University of Connecticut, Storrs CT 06269, OLIVIER DULIEU, Laboratoire Aimé Cotton, CNRS, Orsay, France — Perturbations in photoassociation spectra of ultracold cesium are presented. High precision photoassociation spectra up to 54 cm$^{-1}$ below the Cs$(6S_{1/2})+Cs(6P_{1/2})$ asymptote revealed perturbations related to resonant coupling between electronic states of the same symmetry but belonging to different asymptotes. The perturbations, which are manifested as irregularities in vibrational level spacings, are most pronounced for the 0$^2P_0$ state, but to some extent present in the 1$^3P_0$ and 0$^1D_2$ states, which are also affected by predissociation. Theoretical calculations of perturbations for all three states and found qualitative agreement with the experimental results. Additionally, we present perturbations involving pure long range 0$^2P_0$ state and the dark 2$^2P_0$ state below the Cs$(6S_{1/2})+Cs(6P_{1/2})$ asymptote. Level shifts and additional spectral features are found in this case.

$^1$Partial support by NSF and NATO.

**R1.00037 Ultracold three-boson systems near a Feshbach resonance: the role of large effective ranges**

JUJUN WANG, Dept. of physics, Kansas State University, J.P. D’INCAO, JILA, University of Colorado. Boulder, CO 80309, B.D. ESRY, Dept. of Physics, Kansas State University — We have studied the behavior of ultracold three-boson systems as the effective range is varied from being much smaller than the scattering length to being much larger. Such variations in the effective range allow us to more realistically model the behavior near a Feshbach resonance [Petrov,Jonsson]. We use model two-body interactions and the adiabatic hyperspherical representation to produce effective three-body potentials from which we try to extract universal behavior. The degree to which these three-body systems behave universally will be discussed. To facilitate this, comparisons will be made with the predictions from zero range potential models. Preliminary numerical calculations suggest that such models may be insufficient, but a more complete analysis will be presented.

$^1$Supported by the National Science Foundation.

**R1.00038 Evaporative cooling of potassium atoms**

SHIN INOUYE, Univ. of Tokyo, JUN KOBAYASHI, JST, ERATO, TETSUO KISHIMOTO, Univ. of Tokyo, KIYOTAKA AIKAWA, KAI NODA, TAKUTO ARAE, Univ. of Tokyo, MASASHITOUEDA, Tokyo Inst. of Tech., JST, ERATO — Recent advances in manipulating interactions between ultracold atoms opened up various new possibilities. One of the major goal of the field is to produce ultracold polar molecules. By utilizing a magnetic field induced Feshbach resonance, it is possible to produce heteronuclear molecules from a degenerate gas mixture. We are setting up an experiment to produce a degenerate gas mixture of fermionic alkali atoms, Lithium-6 and potassium-40. Fermionic atoms are good candidate for minimizing the expected inelastic loss at the Feshbach resonance. For keeping the system as simple as possible, we decided to use bosonic potassium (potassium-41) as a coolant, and sympathetically cool the fermionic species. We will present our experimental setup and initial results for evaporatively cooling bosonic potassium atoms.

**R1.00039 Cold collisions of oriented molecules**

E. ABRAHAMSSON, T.V. TSCHERBUL, R.V. KREMS, Dept. of Chemistry, University of British Columbia, Vancouver, B.C., Canada — Orienting molecules with dc electric fields is a versatile technique for studying the mechanisms of inelastic collisions and chemical reactions. Here, we use rigorous quantum theory of collisions in electromagnetic fields [1,2] to study the electron spin relaxation of magnetically trapped $^3\Sigma_g^+$ and $^1\Sigma_u^+$ molecules oriented by electric fields. We demonstrate that inelastic collisions of CsD($^3\Sigma_g^+$) and Nd ($^1\Sigma_u^+$) molecules can be manipulated by varying the strength of the dc electric field as well as the relative orientation between the electric and magnetic fields. The increase of the energy gap between the ground $N=0$ and the first excited $N=1$ rotational levels results in suppression of the spin relaxation at a collision energy of 1 K [1,2]. We also demonstrate that electric fields inhibit rotational relaxation of $^2\Sigma$ molecules [2]. Our results show that (1) sympathetic and evaporative cooling of $^3\Sigma$-molecules in a magnetic trap may be facilitated by applying electric fields and (2) electric fields may induce nonadiabatic transitions in collisions of $^2\Sigma$ molecules with open-shell atoms [2]. The latter result indicates that chemical reactions between atoms and molecules in a magnetic trap can be effectively manipulated by dc electric fields. [1] R.V. Kremes and A. Dalgaro, J. Chem. Phys. 120, 2296 (2004); [2] T.V. Tscherbul and R.V. Kremes, Phys. Rev. Lett. 97, 083201 (2006); J. Chem. Phys. 125, 194311 (2006).

**R1.00040 Electric-Field-Induced Feshbach Resonances in Ultracold Alkali Metal Mixtures**

ZHIYING LI, ROMAN KREMS, University of British Columbia — It is shown that the scattering length of alkali metal atoms in ultracold binary mixtures can be effectively modified by dc electric fields of $\sim$ 30 - 100 kV/cm. The mechanism of electric-field-control of ultracold collisions is based on the interaction of the instantaneous dipole moment of the collision complex with external electric fields. This interaction is dramatically enhanced near p-wave scattering resonances. We present a detailed analysis of Feshbach resonances in ultracold collisions of Li and Cs atoms in the presence of superimposed electric and magnetic fields. We show that the electric-field couplings between s- and p-wave collision channels may not only induce electric-field resonances, but also shift the positions of s-wave magnetic resonances, thereby making the electric field control of ultracold atoms possible even far away from p-wave resonances. In addition, we demonstrate that electric fields may rotate and spin up the collision complex of ultracold atoms at substantial rates leading to anisotropic ultracold scattering. Finally, we explore the effect of the relative orientation of magnetic and electric fields on collision dynamics near Feshbach resonances. References: R. V. Kremes, Phys. Rev. Lett. 96, 123202 (2006); Z. Li and R. V. Kremes, Phys. Rev. A (2007) (in press).

**R1.00041 Temperature and Velocity Measurements Through Fluorescence and Absorption Imaging in Ultracold Neutral Plasmas**

JOSE CASTRO, HONG GAO, PRIYA GUPTA, SAMPAD LAHA, CLAYTON SIMIEN, THOMAS KILLIAN, Department of Physics and Astronomy and Rice Quantum Institute, Rice University, Houston, TX 77005 — Imaging probes are used to characterize Ultracold Neutral Plasmas and determine quantities such as velocity and temperature of both ion and electron species. Absorption imaging studies demonstrate that electron temperature evolution varies depending on the initial electron temperature and plasma density. Absorption imaging shows Doppler broadening due to the combined effects of the radially directed expansion velocity and the random thermal motion of the ions. To distinguish these two quantities, fluorescence imaging of Ultracold Neutral Plasmas is used to produce a spatially-resolved spectrum that is Doppler-broadened due to thermal ion velocity and shifted due to ion expansion velocity. Using these two distinct imaging probes, Ultracold Neutral Plasmas were studied under different initial conditions.

**R1.00042 p-wave Feshbach Molecules**

JOHN GAEBLER, JOHN STEWART, JOHN BOHN, DEBORAH JIN, JILA-University of Colorado — We present evidence for the production and detection of molecules using a p-wave Feshbach resonance between 40K atoms. We have measured the binding energies and lifetimes for these molecules. We find that the binding energies scale linearly with magnetic field near the resonance. At magnetic fields above the resonance we detect quasi-bound molecules with lifetimes set by the tunneling rate through the centrifugal barrier. We discuss the possibility of using a p-wave Feshbach resonance to study BCS-BEC crossover physics with finite angular momentum pairing.

$^1$We acknowledge funding from NSF, NASA, and NIST.
Magueijo points out the role of made to modify general or special relativity (SR) to accommodate a cosmologically decreasing light speed \[ J. Magueijo, Rep. Prog. Phys. 66 \].

For reasons connected with both cosmology (the flatness and horizon problems) and atomic physics (n-body Dirac equation, etc.), various proposals have been largely resolving the controversy. These results were presented in PRL 97, 040801 (2006).

In particular, symmetric SR brings a new light to the Dirac large-number relationship between the constants of gravitation and atomic physics.

Landé g-factor between the \( 1 \) field, the high line \( Q \) of the

University of Colorado — We have performed ultra-high resolution spectroscopy using a

promising alternative to CPT-based clocks due to their high resonance contrast and the potential to cancel first-order light shifts. We present measurements of

with low power consumption and fractional frequency stability of \( 10^{-14} \).

YANHONG XIAO, DAVID PHILLIPS, RONALD WALSWORTH, Harvard-Smithsonian — There is great current interest in developing small atomic clocks are aiming at

clocks are aiming at

fields —

R1.00045 High-accuracy calculation of black-body radiation shift in \( ^{133} \) Cs primary frequency standard \[ 1 \]. KYLE BELOY, ULYANA SAFRONOVA, ANDREI DEREVIANKO, University of Nevada, Reno — Black-body radiation (BBR) shift is an important systematic correction for the atomic frequency standards realizing the SI unit of time. In recent years there has been a controversy over the value of the BBR shift for the primary \( ^{133} \) Cs standard. At room temperatures, reported values from various groups have differed at the \( 3 \times 10^{-15} \) level, while modern clocks are aiming at \( 10^{-16} \) accuracies. We have carried out high-precision relativistic many-body calculations of the BBR shift. For the BBR coefficient \( \beta \) at \( T = 300 \) K we have obtained \( \beta = -(1.708 \pm 0.006) \times 10^{-14} \), implying \( 6 \times 10^{-17} \) fractional uncertainty. While in accord with the most accurate measurement, our 0.35%-accurate value is in a substantial, 10%, disagreement with recent semi-empirical calculations. We have identified an oversight in those calculations, largely resolving the controversy. These results were presented in PRL 97, 040801 (2006).

R1.00047 N-resonance characterization for compact atomic clocks, CINDY HANCOX, IRINA NOVIKOVA, YANHONG XIAO, DAVID PHILLIPS, RONALD WALSWORTH, Harvard-Smithsonian — There is great current interest in developing small atomic clocks with low power consumption and fractional frequency stability of \( 10^{-12}/\sqrt{\tau/s} \) or better. N-resonances, all-optical three-photon-absorption resonances, offer a promising alternative to CPT-based clocks due to their high resonance contrast and the potential to cancel first-order light shifts. We present measurements of the N-resonance contrast, width and light-shift for \( ^{87} \) Rb in a compact (1 mm long) buffer gas vapor cell and a 1 cm long paraffin-coated cell.

R1.00048 Ultra-high resolution spectroscopy with a \( ^{87} \) Sr lattice clock, GRETCHEN K. CAMPBELL, SEBASTIAN BLATT, MARTIN M. BOYD, ANDREW D. LUDLOW, TANYA ZELEVEISKY, SETH M. FOREMAN, THOMAS ZANON, JUN YE, JILA, NIST, and University of Colorado — We have performed ultra-high resolution spectroscopy using a \( ^{87} \) Sr optical lattice clock. With the addition of a small magnetic bias field, the high line Q of the \( 1S_0 \rightarrow 1P_1 \) clock transition has allowed us to resolve the nuclear-spin sublevels, and make a precision measurement of the differential Landé g-factor between the \( 1S_0 \) and \( 1P_0 \) states arising from hyperfine mixing of the \( 1P_0 \) with the \( 3P_0 \) and \( 1P_1 \) states. Breaking the nuclear-spin degeneracy allows for a better characterization of systematic errors, and we have made measurements of these nuclear-spin related effects including the linear Zeeman shift and tensor polarizability. The ability to directly manipulate individual nuclear-spin levels also makes this an attractive system for quantum information. Recent progress towards an all optical comparison of atomic clocks, including the construction of a new strontium three-dimensional optical lattice will also be presented.

R1.00049 Precision Measurements with Matter-wave Interferometry, CHRISTOPHER ERICKSON, DAN CHRISTENSEN, MATTHEW WASHBURN, JAMES ARCHIBALD, MARSHALL VAN ZIJL, JEREMIAH BIRRELL, ADAM BURDETT, DALLIN DURFEE, Brigham Young University — We will discuss progress on a neutral-calcium beam interferometer which is nearing completion. We will also present a proposal to measure electric and magnetic fields with extreme precision using a slow ion interferometer. The calcium interferometer utilizes a thermal beam for simplicity and high atom flux. Doppler shifts will be reduced using a novel alignment scheme for the Ramsey beams using precision prisms. The ion interferometer will utilize a slow beam of strontium-87 ions created by photon-ionizing a slow atomic beam. The ions will interact with three sets of laser beams which will drive stimulated Raman transitions. The proposed device will be used to search for variations from Coulomb’s inverse-square law and a possible photon rest mass with a precision which is several orders of magnitude better than previous laboratory experiments.

R1.00050 Measurement of a forbidden magnetic dipole matrix element in Rb, T. TAKEKOSHI, R.J. KNIZE, US Air Force Academy — For non-relativistic wavefunctions, the Rb 5S to 6S transition is E1 and M1 forbidden. For relativistic wavefunctions, the leading term is M1. The value of this lowest nS to (n+1)S matrix element has been calculated for all of the alkali atoms using relativistic many-body perturbation theory by Savukov, Dervievanko, Berry, and Johnson [PRL 83 2914 (1999)]. Their predicted value of the Cs 6S to 7S matrix element is within 16% of the high-precision (<1%) value measured by Bennett and Wieman [PRL 82 2484 (1999)]. The Rb 5S to 6S M1 matrix element is predicted to be especially sensitive to contributions from negative-energy states. Including negative-energy states changes the calculated value by 60%. We attempt a measurement of this matrix element at the 10% precision level to investigate this effect.
This extended atom trap is molasses, becoming trapped in the 1D lattice, which can then be loaded with multiple launches. With atoms stretched out over 5 cm, the effective volume of the build-up cavity of light. It provides a transverse guide depth of 150 μm.

We demonstrate a 90 cm launch of Cs atoms guided by a one-dimensional (1D) optical lattice. The 1064 nm wavelength optical lattice is made in a 2 m liquid nitrogen temperature or below both during and between measurements.

— Laser cooled and trapped radioactive atoms provide an ideal sample for studying parity violation in beta decay. We present recent progress in undertaking a high precision beta-recoil measurement of radioactive 82Rb atoms in an optical tweezer. We have demonstrated the loading of 82Rb atoms from a magneto-optical trap (MOT) to a far off resonance dipole trap formed by a YAG laser. A preliminary study of the trap loading efficiency and optical pumping into a stretched state will be presented. In our improved beta asymmetry measurement, we plan to load 82Rb atoms from a MOT into an optical dipole tweezer and then beam the atoms down to a science chamber where the atoms will be polarized and their beta decay measured.

— We present the new generation of Magnetic Sublevel Coherences for Precision Measurements. I. CHAN, York University, S. BEATTIE, Beattie, A. KUMARAKRISHNAN, York University — We have solved the density matrix rate equations for atoms interacting with laser fields that create coherences between adjacent magnetic sublevels of the F=3 ground state in 85Rb. The rate equations are solved in an irreducible tensor basis and allow us to calculate the polarization of the atoms as a function of time after interaction with the laser fields. We include all the states in the excited hyperfine manifold, assume that the magnetic sublevels are degenerate and compare the results with experiments using laser-cooled atoms. We also describe the effect of a magnetic field on this system as a time dependent rotation about the quantization axis. The rotation matrix is written in terms of the Euler angles and the results are useful in modeling the signals used to measure the atomic g factor ratio using 85Rb and 87Rb isotopes. We also compare the results obtained for the magnetic field dependence using Rb vapour at room temperature.

— On the possibility of considering the fullerene shell C60 as a conducting sphere, MIRON AMUSIA, Racah Institute of Physics, The Hebrew University, Jerusalem 91904, Israel, ARKADIY BALTENKOV, Arkivof Institute of Electronics, Tashkent, 700125, Uzbekistan — It has been shown that the fullerene shell in the static electric field behaves as a set of separate carbon atoms, rather than a conducting sphere [1]. We calculate the effective electric field $E_{eff}(ω)$ at the fullerene center when the external $E(ω)$ with frequency $ω$ is applied to C60. The modification of the external field comes from the effect of the dynamic dipole polarizability $α_d(ω)$ of the fullerene C60 expressed via its total photionization cross-section $σ(ω)$[2]. We calculate the ratio $η(ω) ≡ E_{eff}(ω)/E(ω)$ and then investigate whether $η(0)$ is equal to zero. The equality of the ratio $η(ω)$ to zero in the static limit $ω → 0$ is the critical condition being general for a conducting body with any form. For C60 this ratio is $η(0) ≃ 2$, i.e. C60 is not a hollow metallic sphere. It is shown that at any $ω$ the frequency dependence of the ratio of the fields $η(ω)$ at the center of the C60 molecule and outside it has nothing to do with $η(ω)$ for the conducting sphere [1], which is additional evidence that the C60 shell is strongly non-metallic. [1] J.-P. Connerade and A. V. Solov’yov, J. Phys. B 38, 807 (2005) [2] J. Berkowitz, J. Chem. Phys. 111, 1446 (1999).
R1.00058 Long-range interactions between three P-state atoms in a magnetic field. SERGEY AILYABYSHEV, ROMAN KREMS, Department of Chemistry, University of British Columbia, Vancouver, B.C. V6T 1Z1, Canada — Using the spherical tensor expansion of the interaction potential between two open-shell atoms [1], we analyze adiabatic potential energy surfaces for three atoms in the 3P2 state in the presence of an external magnetic field. It is shown that anisotropic quadrupole-quadrupole interactions between three open-shell atoms may result in long-range repulsions due to avoided crossings between adiabatic surfaces correlating with different atomic states. The strength of the long-range repulsion depends on the magnitude of the applied magnetic field. [1] J.R. V. Krems, G. C. Groenenboom, and A. Dalgarno, Phys. Chem. A 108, 8941 (2004)

R1.00059 Complete Single–Center Basis Sets in Atomic Calculations1, SCOTT I. YOUNG, KYLIE ROLLIN, MICHAEL W.J. BROMLEY, Department of Physics, San Diego State University, JIM MITROY, Faculty of Technology, Charles Darwin University, KU-RUNTHAN RATHNAVELU, Faculty of Science, Universiti Malaya, Kuala Lumpur — Single particle orbitals centered on the nucleus are the most commonly used basis in large-scale calculations of atomic structure. The convergence towards a complete basis set, with respect to both the number and angular momenta of the orbitals included in a configuration interaction (CI) expansion, has been investigated using the ground and excited states of the helium atom [1,2,3]. This enabled energies to be determined to within 10−8 Hartree, whilst the convergence of the electron-electron δ-function and other relativistic corrections have been examined in detail. Unusual convergence patterns in the CI-Kohn variational scattering method have been observed and, however, high-precision calculations of elastic positron scattering from atoms are achievable [4].

1Supported in part by the Australian Research Council.

R1.00060 Precision Hyperfine Structure of 2 3P State of 3He with External Magnetic1, QIXUE WU, G.W.F. DRAKE, University of Windsor — The theory of the Zeeman effect can be used to extrapolate precise measurements for the fine structure of the hyperfine structure to zero-field strength. In the present work, the hyperfine structure of 2 3P state of 3He with external magnetic fields is precisely calculated. The values of the fields for 32 crossings and five anticrossings of the magnetic sublevels are theoretically predicted for magnetic field strengths up to 1 Tesla. The results are compared with experimental work. We include the linear terms, diamagnetic terms, and the α/2- relativistic correction terms in the Zeeman Hamiltonian. All related matrix elements are calculated with high accuracy by the use of double basis set Hylleraas type variational wave functions [1,2].

1Supported by NSERC.

R1.00061 Experimental nonlinear studies of atoms and molecules with an intense VUV-photon source. JEROEN VAN TILBORG, TOM ALLISON, MARCUS HERTLEIN, THORSTEN WEBER, ANDREW AQUILA, Lawrence Berkeley National Laboratory, SASA BAJT, Lawrence Livermore National Laboratory, ROGER FALCONE, ALI BELKACEM, Lawrence Berkeley National Laboratory — Photons of energy in the 30–100 eV range can interact with core electronic states in atoms and small molecules. Through high-harmonic generation (HHG) by a terawatt near-infrared laser, such photons can now be delivered as energetic and ultra-short pulses (>10 pJ in <50 fs). After focusing of such VUV pulses, peak intensities can reach 1013–1014 W/cm2, enabling nonlinear processes such as two-photon absorption to become detectable. In addition, intrinsic synchronization between laser and VUV photons allows for ultra-fast pump-probe experiments. The challenge in realizing these high harmonic pulses lays in phase matching, source optimization, separation of laser- and VUV-pulse, and their spectral and spatial characterization. Detailed information about these issues and their solution at LBNL will be presented. On the application side, the latest results as well as planned experiments will be discussed. Such experiments include two-photon absorption of core electrons in Xenon, where a quadrupole giant resonance is expected, and two-photon double-ionization experiments on atoms and molecules.

R1.00062 PHOTON INTERACTIONS WITH ATOMS, IONS, AND MOLECULES — R1.00063 Photoionization spectroscopy of even-parity autoionizing Rydberg states of argon atoms1, J.D. WRIGHT, T.J. MORGAN, Physics Department, Wesleyan University, Q. GU, L. LI, J.L. KNEE, Chemistry Department, Wesleyan University — We use the J=0 and J=2 metastable states of argon created in a plasma discharge to perform photoionization spectroscopy of even-parity autoionizing Rydberg states of the argon atom between the first and second ionization limits. Fitting the data to a linear combination of Fano-type peaks allows us to extract the widths and q-parameters of the resonances. Finally, we compare the experimental profile of p-type multipolets to the results of recent theoretical calculations [1]. Agreement is good.

1Supported by the National Science Foundation.

R1.00064 Space and Time Resolved Continuum Correlation in the Post-Collision Interaction of Core-Photoionized Neon1, A. BHANDARY, A.L. LANDERS, F. ROBICHEAUX, Auburn University, T. OSIPOV, M. HERTLEIN, M.H. PRIOR, A. BELKACEM, Lawrence Berkeley National Laboratory, P. RANITOVIC, I. BOCHAROVA, C.L. COCKE, Kansas State University, T. JAHNKE, M. SCHOFFLER, J. TITZE, R. DORNER, University of Frankfurt — We have used the COLTRIMS∗ technique to measure the momentum distribution of the photoelectron and the recoil ion produced by the core-photoionization of neon. Conservation of momentum allows us to determine the subsequent auger electron’s momentum that is emitted when the Ne+ relaxes to the Ne2+ state. Momentum space plots of the electrons and the recoil ion are then used to resolve the three-body correlated post-collision interactions in space and time. Finally, classical calculations have been performed which corroborate our interpretation of the experimental results.


1Supported by the Chemical Sciences, Geosciences and Biosciences Division, Office of Basic Energy Sciences, Office of Science, U.S. Department of Energy
R1.00065 Photoionization of Se+ and Se2+ Ions: Experiment and Theory. D.A. ESTEVES, University of Nevada, Reno, NV, N.C. STERLING, NASA-GSFC Greenbelt, MD, GHAZZAN ALNA’WASHI, University of Nevada, Reno, NV, A. AGUILAR, A.L.D. KILCOYNE, LBL-ALS Berkeley, CA, C.P. BALANCE, Rollins College, Winter Park, FL, P.H. NORTINGTON, B.M. MCLAUGHLIN, Queen’s University of Belfast, UK — The determination of elemental abundances in astrophysical nebulae are highly dependent on the accuracy of the available atomic data. Numerical simulations show that derived Se abundances in ionized nebulae cannot be unique by factors of two or more from atomic data uncertainties alone. Of these uncertainties, photoionization cross section data are the most important, particularly in the near threshold region of the valence shell. Absolute photoionization cross sections for Se+ and Se2+ ions near their thresholds have been measured at the Advanced Light Source in Berkeley, using the merged beams photo-ion technique. Theoretical photoionization cross sections were performed for both of these Se ions using the state-of-the-art fully relativistic Dirac R-matrix code (DARC). The calculations show encouraging agreement with the experimental measurements. A more comprehensive set of results will be presented at the meeting.

R1.00066 Experimental Identification of Specific Spin-Orbit Coupling Mechanisms During Photoionization. J.R. MACHAČEK, T.J. GAY, D.H. JAECKS, University of Nebraska-Lincoln, K.W. MCLAUGHLIN, Loras College, O. YENEN, University of Nebraska-Lincoln — Recent fluorescence polarimetry experiments have shown that even with a relatively light target like Ar, large relativistic effects are surprisingly common in photoionization. We show how dynamic magnetic effects during photoionization can be specifically identified as target spin-orbit coupling, target spin-continuum orbit coupling, or continuum spin-orbit coupling, the latter being the Fano effect. Our analysis involves the extraction of partial-wave cross sections from experimental polarization measurements for excited residual ion fluorescence. We demonstrate the application of this technique for fluorescence from the fine-structure resolved states of Ar+ 3p6[3P] 4p2 D3/2, 4P3/2, 4D5/2. Support provided by the NSF (Grants PHY-0354946 and PHY-0098545) and the DOE (LBIN/ALS).

R1.00067 Single and double photoionization of the laser-excited 6s6p 1P0 state of Barium1. JOHN R. TOLSLMA, Department of Physics and JILA, University of Colorado, Boulder, Colorado 80309-0440, CHRIS H. GREENE, Department of Physics and JILA, University of Colorado, Boulder, Colorado 80309 - 0440, USA — We calculate the photoionization cross sections of the 6s6p 1P0 state of barium by either one or two photons. In both cases the final state energies reach the vicinity of the 5d ionization thresholds. This study uses variational R-matrix and quantum defect techniques to calculate the rich array of autoionizing resonances in this energy range. The two-photon cross section calculation utilizes Siegert pseudostates to describe the intermediate levels that arise in the second-order perturbation expansion.

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

R1.00068 Photoelectron angular distribution measurements from α-electron photodetachment of Lu−. A.M. COVINGTON, Physics Department, University of Nevada, Reno, S.S. DUVVURI, E.D. EMMONS, R.G. KRAUS, J.S. THOMPSON, Physics Department, University of Nevada, Reno, V.T. DAVIS — The spectral dependence of the angular distributions of photoelectrons produced by the single-photon photodetachment process hν+ Lu− (Xe)1f146s66d6 (D2) → Lu (Xe)1f146s66d5 (D2) + e−, have been measured at discrete photon wavelengths ranging from 457.9 to 532 nm (2.71–2.33 eV) using a crossed laser-ion beam apparatus. An intense 10 keV Lu− beam was crossed at 90◦ with a linearly polarized, continuous photon beam in order to produce photoelectrons. Photoelectron yields were measured as a function of the orientation of the laser polarization vector with respect to the momentum vector of the collected photoelectrons. The photoelectron angular distributions were used to determine asymmetry parameters. The spectral variation of the asymmetry parameter is shown to be consistent with the photodetachment of a alpha-electron using the model of Hanstorp etal [Phys. Rev. A 40, 670 (1989)], and acts to verify the Lu− ground state configuration predicted by Eilth etal [Phys. Rev. A 52, 291 (1995)].

R1.00069 Tunable Laser Photodetachment Spectroscopy of Ce−1. N.D. GIBSON, C.W. WALTER, C.M. JANCZAK, K.A. STARR, A.P. SNEDDEN, R.L. FIELD, Denison University, P. ANDERSSON, Gothenburg University, Sweden — The relative cross section for photodetachment from Ce− was measured over the photon energy range 0.5 – 2.6 eV. Neutral atom production was measured as a function of photon energy for both long range survey scans and high resolution scans over interesting spectral features. The spectra reveal several continuum features likely associated with thresholds for opening detachment channels near 0.7 eV, 0.9 eV, and 1.3 eV. Five sharp peaks were observed over the range 0.61 – 0.71 eV and their energies and widths were determined by fitting with Fano profiles. The results are compared to recent experimental [1] and theoretical [2] results for the electron affinity of Ce and the photodetachment spectrum of Ce−. [1] V.T. Davis and J.S. Thompson, Phys. Rev. Lett. 88, 073003 (2002). [2] S.M. O’Malley and D.R. Beck, Phys. Rev. A 74, 042509 (2006); X. Cao and M. Dolg, Phys. Rev. A 69, 042508 (2004).

1 This material is based on work supported by the National Science Foundation under Grant No. 0456916.

R1.00070 Dynamical and relativistic effects in experimental and theoretical studies for inner-shell photoionization of sodium1. D. CUBAYNES, J.-M BIZAU, S. DIEHL, F.J. WUILLUEMIER, University paris-Sud, Orsay, France, H.-L. ZHOU, S.T. MANSON, Georgia State University, A. HIBBERT, Queen’s University of Belfast, N. BERRAH, S. CANTON, Western Michigan University, J.D. BOZEK, Lawrence Berkeley laboratory, E.T. KENNEDY, Dublin City University, Dublin, Ireland, L. VOKY, Observatoire de Paris, France, X.-Y. HAN, Tsinghua University, Beijing, China — High-resolution measurements for inner-shell photoionization of Na ground state over a 40-120 eV photon energy are presented along with the results of a semi-relativistic Breit-Pauli R-matrix calculation. The comparisons show excellent agreement generally, that gives a demonstration that the calculation includes the important relativistic and correlation effects. Relativistic effects are significant primarily in the neighborhood of narrow resonances. The importance of “balancing” the correlation included in initial and final state wave functions is emphasized.

1 This work was supported by DOE and NSF.

R1.00071 Calculation of inner-shell photoionization of ground state Na: relativistic vs. non-relativistic calculation1. H.-L. ZHOU, S.T. MANSON, Georgia State University, A. HIBBERT, Queen’s University of Belfast — Calculations of inner-shell photoionization of ground state Na over the photon energy range 40-100 eV have been performed using nonrelativistic LS coupling and relativistic Breit-Pauli (BP) R-matrix approximations. The BP R-matrix calculation adds the spin-orbit, mass-correction and Darwin terms to the non-relativistic Hamiltonian in order to include relativistic effects, giving 11 J-dependent states of Na+ from 61 LS states; the same target orbitals are used for both calculations. The calculated energy of ground state of Na is 5.1066 eV in LS coupling and 5.1756 eV in BP approximation ( NIST value is 5.14 eV). We find that in the neighborhood of the broad 2s—np resonances, the results of LS and BP calculations are almost same, but in the neighborhood of narrow doubly-excited 2p8nln’ resonances, the BP calculations show spin-orbit splitings and differ significantly from the LS coupling results.

1 This work was supported by DOE and NSF.
R1.00072 Photo double detachment of CN\(^-\): Electronic decay from an inner-valence hole in molecular anions\(^1\). R.C. BiloDEau, Western Michigan University and Lawrence Berkeley National Laboratory - ALS, C.W. Walter, Denison U., I. DumITRIU, WMU and LBNL, N.D. GIBSON, Denison U., G.D. ACKERMAN, J.D. BOZEK, B.S. RUDE, LBNL, R. SANTRA, Argonne National Lab. and ITAMP, L.S. CederBEaum, U. Heidelberg, N. BeraRRa, WMU — The first measurements of inner-valence photodetachment from CN\(^-\) as well as theoretical calculations around the 2-electron threshold (25–90 eV) will be presented. Measured absolute cross sections for CN\(^+\) production by photo double detachment of CN\(^-\), and for C\(^+\) and N\(^+\) fragments produced from the dissociation of the excited molecule will be reported. The measurements also reveal the signature of inner-valence autoionization, similar to the interatomic Coulombic decay (ICD) phenomenon. This work confirms the predicted effect, which should in general be present for molecular anions, even in very small molecules.

\(^1\)This work is funded by DOE, office of Science, BES, Chemical Sciences, Geosciences and Biosciences Divisions, and the National Science Foundation.

R1.00073 Inner Shell Studies in Transition Metal Negative Ions: d-shell Photoexcitation and Detachment\(^1\). R.C. BiloDEau, Western Michigan U. and Lawrence Berkeley National Laboratory - ALS, I. DumITRIU, WMU and LBNL, N.D. GIBSON, Denison U., J.D. BOZEK, SLAC, Z.D. PESIC, D. ROLLES, WMU and LBNL, N. BERRAHA, WMU — Results of the first inner-shell photoexcitation and detachment studies conducted on the transition metal negative ions will be presented. The experiments were conducted on Ru\(^-\), Ni\(^-\), Pd\(^-\), and Pt\(^-\) near the ns, np shells (n=3 for Ni, 4 for Ru and Pd, 5 for Pt), and 4f shell (in Pt). All ions show significant probabilities for multi-electron ejection in the detachment and decay mechanisms, with a total of up to 4 electrons removed. Excitation of a p-electron into the nearly-filled d-shell (in Ru\(^-\), Ni\(^-\), and Pt\(^-\)) results in strong shape resonances, and excitation of a 4f-electron gives rise to conspicuous Feshbach resonances in Pt\(^-\). In contrast, no resonances are observed in Pd\(^-\), owing to its completely filled valence 4d shell, in spite of being in the same group as Ni and Pt.

\(^1\)This work is funded by DOE, office of Science, BES, Chemical Sciences, Geosciences and Biosciences Divisions, and the National Science Foundation.

R1.00074 Time-dependent localized Hartree-Fock density-functional theory for photoionization processes of excited states of atomic systems\(^1\). ZhONGYUAN ZHOU, SHIH-I. CHU, Department of Chemistry, University of Kansas, Lawrence, KS 66045 — We propose a time-dependent localized Hartree-Fock density-functional approach for the treatment of photoionization processes of excited states of atomic systems. In this approach, Kohn-Sham (KS) equation with a spin-dependent localized Hartree-Fock (SLHF) potential being used as its exchange potential is solved to obtain electron spin-orbitals and orbital energies from which linear response function induced by an external radiation field is calculated and photoionization process is studied. The SLHF potential has good long-range behavior and thus allows one to treat the high-lying Rydberg states accurately. For demonstration, we apply this approach to calculate photoionization cross sections, linewidths, and resonance parameters of Ne. The results are in good agreement with experimental data and other theoretical calculations. We also present for the first time the photoionization cross sections of highly excited and inner-shell excited states of Ne.

\(^1\)Supported by DOE and NSF.

R1.00075 Electron affinity and photodetachment calculations of Nd\(^-\)\(^1\), STEVEN M. O'MALLEY, DONALD R. BECK, Physics Department, Michigan Technological University — Our recent relativistic configuration-interaction (RCI) calculations for the bound states of Ce\(^3\) have shown the usefulness of analysis which combines calculated photodetachment cross sections with experimental measurements\(^2\). Here we present RCI results for 8 weakly bound (≤ 0.2 eV) states of Nd\(^-\) (6p attachments to 4f\(^6\)6s\(^2\)). Photodetachment cross sections involving excited states of Nd\(^-\) are expected to resolve the discrepancy with the available experimental electron affinity of 1.916 eV\(^2\). Additional improvements of our methodology are also discussed.

\(^2\)Supported by the National Science Foundation, Grant No. PHY-0097111.

R1.00076 Non-dipole angular anisotropy parameters of photoelectrons from semi-filled shell atoms, MIRON YA AMUSIA\(^1\), LARISSA V. CHERNYsheva, Joffe Physical-Technical Institute, St.-Petersburg 194021, Russia — We present the results of calculations of outer and next to the outer shell non-dipole angular anisotropy parameters of photoelectrons for semi-filled shell atoms in the Hartree-Fock one-electron approximation and in the frame of the Spin Polarized Random Phase Approximation with Exchange. We consider photoelectrons from semi-filled and closed shells that are neighbours. We studied also photoelectrons from Cr\(^+\) and Mo\(^+\) that are formed by spin-flip of the outer s- electrons. To see the role of the nuclear charge variation, we have treated the case of 3p -electrons in K, Ar and K\(^+\). The following subshell were considered: N (2p), P (3p), Ar (3p), K\(^+\) (3p), K(3p), Cr(3p), 3d, Cr\(^+\) (3d), Mn(3p, 3d, As(3d, 4p), Mo(4p, 4d), Mo\(^+\) (4d), Tc(4p, 4d), Sb(4d, 5p), Eu(4f)). The detailed information can be found in [1]. The peculiarities of obtained parameters as functions of photon frequency are quite prominent and deserve experimental investigation.


R1.00077 Dipole angular distribution and spin polarization of photoelectrons from semi-filled shell atoms, MIRON AMUSIA\(^1\), Racah Institute of Physics, The Hebrew University, Jerusalem 91904, Israel

R1.00078 Inner-valence autoionization, similar to the interatomic Coulombic decay (ICD) phenomenon. This work confirms the predicted effect, which should in general be present for molecular anions, even in very small molecules.

R1.00079 Photodetachment cross sections involving excited states of Nd\(^-\) are expected to resolve the discrepancy with the available experimental electron affinity of 1.916 eV\(^2\). Additional improvements of our methodology are also discussed.

R1.00080 Non-dipole angular anisotropy parameters of photoelectrons from semi-filled shell atoms, MIRON YA AMUSIA\(^1\), LARISSA V. CHERNYsheva, Joffe Physical-Technical Institute, St.-Petersburg 194021, Russia — We present the results of calculations of outer and next to the outer shell non-dipole angular anisotropy parameters of photoelectrons for semi-filled shell atoms in the Hartree-Fock one-electron approximation and in the frame of the Spin Polarized Random Phase Approximation with Exchange. We consider photoelectrons from semi-filled and closed shells that are neighbours. We studied also photoelectrons from Cr\(^+\) and Mo\(^+\) that are formed by spin-flip of the outer s- electrons. To see the role of the nuclear charge variation, we have treated the case of 3p -electrons in K, Ar and K\(^+\). The following subshell were considered: N (2p), P (3p), Ar (3p), K\(^+\) (3p), K(3p), Cr(3p), 3d, Cr\(^+\) (3d), Mn(3p, 3d, As(3d, 4p), Mo(4p, 4d), Mo\(^+\) (4d), Tc(4p, 4d), Sb(4d, 5p), Eu(4f)). The detailed information can be found in [1]. The peculiarities of obtained parameters as functions of photon frequency are quite prominent and deserve experimental investigation.


R1.00079 Dipole angular distribution and spin polarization of photoelectrons from semi-filled shell atoms, MIRON AMUSIA\(^1\), Racah Institute of Physics, The Hebrew University, Jerusalem 91904, Israel

R1.00080 Inner-valence autoionization, similar to the interatomic Coulombic decay (ICD) phenomenon. This work confirms the predicted effect, which should in general be present for molecular anions, even in very small molecules.

R1.00081 Photodetachment cross sections involving excited states of Nd\(^-\) are expected to resolve the discrepancy with the available experimental electron affinity of 1.916 eV\(^2\). Additional improvements of our methodology are also discussed.

R1.00082 Non-dipole angular anisotropy parameters of photoelectrons from semi-filled shell atoms, MIRON YA AMUSIA\(^1\), LARISSA V. CHERNYsheva, Joffe Physical-Technical Institute, St.-Petersburg 194021, Russia — We present the results of calculations of outer and next to the outer shell non-dipole angular anisotropy parameters of photoelectrons for semi-filled shell atoms in the Hartree-Fock one-electron approximation and in the frame of the Spin Polarized Random Phase Approximation with Exchange. We consider photoelectrons from semi-filled and closed shells that are neighbours. We studied also photoelectrons from Cr\(^+\) and Mo\(^+\) that are formed by spin-flip of the outer s- electrons. To see the role of the nuclear charge variation, we have treated the case of 3p -electrons in K, Ar and K\(^+\). The following subshell were considered: N (2p), P (3p), Ar (3p), K\(^+\) (3p), K(3p), Cr(3p), 3d, Cr\(^+\) (3d), Mn(3p, 3d, As(3d, 4p), Mo(4p, 4d), Mo\(^+\) (4d), Tc(4p, 4d), Sb(4d, 5p), Eu(4f)). The detailed information can be found in [1]. The peculiarities of obtained parameters as functions of photon frequency are quite prominent and deserve experimental investigation.


R1.00078 Photodetachment of Lanthanide Oxide Anions. A.M. COVINGTON, E.D. EMMONS, R.G. KRAUS, J.S. THOMPSON, Physics Department, University of Nevada, Reno, Reno NV 89557-0058, D. CALABRESE, Sierra College, Rocklin, CA 95677, V.T. DAVIS, Defense Threat Reduction Agency CXT2-Det 2, West Desert Test Center, Dugway, UT 84022-5000 — Laser photodetached electron spectroscopy (LPES) has been used to study the structure and collision properties of lanthanide oxide anions including LaO\(^{-}\) and CeO\(^{2-}\). Preliminary photoelectron spectra from these anions will be presented along with ion beam production data from these and other lanthanide oxide anions.

R1.00079 Ionization and Dissociation of N\(_2\) from 17.5 to 36.5 eV by Linearly and Circularly Polarized Light. J.E. FURST, University of Newcastle-Ouimbah, T.J. GAY, University of Nebraska-Lincoln, H. GOULD, A.L.D. KILCOYNE, LBNL, J.R. MACHACEK, University of Nebraska-Lincoln, K.W. MCLAUGHLIN, Loras College — We have measured the linear (P\(_{\perp}\)) and circular (P\(_{\parallel}\)) polarization of the fluorescence emitted in the B\(^2\Sigma^+\rightarrow X\(^2\Sigma^+\) (\nu' = 0, \nu'' = 0) transition (391.4 nm) of N\(^{+}\) after photoionization of N\(_2\) by both linearly and circularly polarized UV radiation. The value of P\(_{\parallel}\) for linearly polarized excitation is in qualitative agreement with previous results [1]. Results for circularly-polarized excitation show significantly different energy dependence. In this energy range, photofragmentation into neutral atoms caused by the predissociation of doubly-excited Rydberg states via non-Rydberg doubly-excited resonances competes with photoionization [2]. We have measured the intensity and a distinct non-zero P\(_{\parallel}\) of the fluorescence from the N\(_2\) 3\(^2\)P\(^+\) - 3\(^4\)P\(^+\) transition (818 nm) between 22.5 and 25 eV which corresponds to the initial excitation of the N\(_2\) Rydberg R(C) states. [1] J. A. Guest et al., Phys. Rev. A 28, 2217 (1983) [2] P. Erman et al., Phys. Rev. A 60, 426 (1999) Support provided by the NSF (Grant PHY-0354946), the DOE (LBNL/ALS) and the ANSTO (Access to Major Research Facilities Programme).

R1.00080 Photoionization of Xe 3d electrons in molecule Xe@C\(_60\) — interplay of intra-doublet and confinement resonances. MIRON YA AMUSIA. Racah Institute of Physics, The Hebrew University, Jerusalem 91904, Israel, ARKADIY S. BALTENKOV, Afnor Institute of Electronics, Tashkent, 700125, Uzbekistan, LARISSA V. CHERNYŞHEVA, Ioffe Physical-Technical Institute, St.-Petersburg 194021, Russia — We demonstrate rather interesting manifestations of co-existence of resonance features in characteristics of the photoionization of 3d-electrons in Xe@C\(_60\). It is shown that the reflection of photoelectrons produced by the 3d Xe photoionization affects greatly partial photoionization cross-sections of 3d\(_{3/2}\) and 3d\(_{5/2}\) levels and respective angular anisotropy parameters, both dipole and non-dipole adding to all of them additional maximums and minimums. The calculations are performed taking into account the corresponding effects of atomic orbitals in the frame of the "orange" skin potential model. It is essential that in the considered photon frequency region presented resonance features are not affected by the C\(_60\) polarization. For details see http://arxiv.org/abs/physics/0609121.

R1.00081 NEW THEORETICAL AND EXPERIMENTAL TECHNIQUES: APPLICATIONS OF AMO SCIENCE; NONLINEAR DYNAMICS

R1.00082 Exact Quantum Treatment of Continuum Electrons. TECK-GHEE LEE, Oak Ridge National Lab and U of Kentucky, S. YU OVCHENIKOV, Oak Ridge National Lab and U of Tennessee, JAMES STERNBERG, V. CHUPRYNA, U of Tennessee, D.R. SCHULTZ, Oak Ridge National Lab, H. MACEK, Oak Ridge National Lab and U of Tennessee. — An exact three-dimensional (3D) quantum mechanical treatment is presented for the evolution of continuum electrons in the fields of moving ions. The novel method introduced here allows one to propagate the continuum electrons to asymptotically large interstellar distances and obtain stable ejected electron momentum spectra. As a result, our computations resolve long standing controversies concerning top-of-barrier, superpromotion and cusps electron momentum distributions. While the method is employed for protons impact ionization of atomic hydrogen, it is general and readily applied to any problems involving electron motion in the presence of time-dependent external fields.

R1.00083 Hyperangular Green’s functions and the three body problem\(^1\). SETH T. RITTENHOUSE, Department of Physics and JILA, University of Colorado, Boulder, CO 80309, NIRA\(_V\) P. MEHTA, J.P. D’INCAO, JILA, University of Colorado, Boulder, CO 80309. — A Green’s function approach is formulated and used to determine adiabatic hyperspherical potential curves. The Green’s function is found for the hyperangular part of the non-interacting Schroedinger equation with any number of particles in any number of dimensions. This Green’s function is then applied to the three-body problem with regularized, zero-range, pairwise, s-wave interactions, which determine a quantization condition whose solution yields the adiabatic potential curves for any given total angular momentum and exchange symmetry. This method appears to generalize readily to handle multichannel, regularized, zero-range, pairwise interactions.

\(^1\)This work was supported by NSF funding.

R1.00084 Thermalization of Suprathermal N(S) atoms in He and Ar gases. PENG ZHANG, ALEXANDER DALGARNO, ITAMP, Harvard-Smithsonian Center for Astrophysics — The thermalization of hot nitrogen atoms in the He and Ar buffer gases is investigated. We calculate the rates of energy relaxation of fast nitrogen atoms and provide simple interpolative formulas for the N(S) thermalization rates. The method of determination of the energy relaxation rate is based on the numerical solution of the Boltzmann kinetic equation, describing the evolution of the time-dependent distribution functions of fast nitrogen atoms. The rates of energy transfer in N(S) \(+\) He and Ar collisions are determined using quantally computed differential cross sections of elastic collisions. Theoretical data on the energy relaxation of hot N(S) atoms are compared with the results of recent experiments on the thermalization of fast N(S) atoms in He and Ar buffer gases. The laboratory measurements of the Doppler shifts of the laser induced fluorescence of hot N(S) atoms provide detailed information on the time-evolution of energy distribution functions of N(S) atoms, and we employ these data for testing the theoretical predictions. Results of our ab initio calculations are in good agreement with experimental data. We report also the parameters of the simplified hard sphere model, which describes effective energy relaxation rates of hot N(S) atoms, thermalizing with initial energies between 0.05 and 5 eV in different gases.

R1.00085 Anti-relaxation Surface Coatings for High-Density Alkali-Metal Magnetometers. SCOTT SELTZER, MICHAEL ROMALIS, DAVID RAMPULLA, STEVEN BERNASEK, Princeton University, SANDRINE RIVILLON, YVES CHABAL, Rutgers University — Anti-relaxation surface coatings eliminate the need for buffer gas in alkali-metal vapor cells, giving larger signals due to narrower optical linewidths as well as reduced sensitivity to magnetic field gradients. Paraffin and other coatings presently used to reduce surface relaxation typically cannot operate at the high temperatures (T\(>\)100°C for cesium and T\(>\)150°C for potassium) required to obtain alkali-metal density suitable for spin-exchange relaxation free (SERF) magnetometers. We have found that octadecyltrichlorosilane (OTS) coating can allow approximately 2000 collisions of a potassium atom with the cell walls before depolarization. OTS can operate at temperatures of at least 150°C in the presence of potassium, and we have demonstrated a SERF magnetometer using an OTS-coated cell. We have also developed a reusable alkali vapor cell for simultaneous testing of multiple coated surfaces, and we are presently investigating several other coatings for chemical resistance to alkali metals, antirelaxation properties, and high-temperature operation. Development of a robust, high-temperature anti-relaxation surface coating would allow many experiments using very optically thick alkali vapor with a long spin relaxation time.
transition problems in the nonequilibrium system. The magnetometer was used to detect $^{14}$N NQR signal from powdered ammonium nitrate at 423 kHz, with sensitivity an order of magnitude higher than with a conventional room temperature pickup coil with comparable geometry. The demonstrated sensitivity of 0.24 ft/Hz$^{1/2}$ can be improved by several means, including use of higher power lasers for pumping and probing. Our technique can potentially be used to develop a mobile, open-access NQR spectrometer for detection of nitrogen-containing solids of interest in security applications.

R1.00087 An open-access, low-field MRI system for human lung imaging with hyperpolarized 3He. LEO TSAI, MATTHEW ROSEN, CHIH-HAO LI, ANA BATRACHENKO, ROSS MAIR, RONALD WALSWORTH, Harvard-Smithsonian — The human lung is exquisitely sensitive to gravity and posture. However, conventional high-field magnets used for hyperpolarized noble gas MRI of the human lung restrict subjects to lying horizontally. We have built an open-access, low-magnetic-field ($<5$ mT) MRI instrument which allows freedom of body positioning while providing high-resolution lung images. We have performed 3He lung MRI of human subjects in both the supine and upright positions; and used these images to make the first-ever maps of the heterogeneous distribution of oxygen in the human lung in an upright position.

R1.00088 Phase noise compensation in optical fiber delivery of narrow-linewidth optical frequency standard. WON-KYU LEE, CHANG YONG PARK, HO SUHNG SUH, DAHYUN YUM, MYOUNG-SUN HEO, YOUNGHEE KIM, WONHO JHE, Seoul National University, HEUNG-RYOUL NOH, Chonnam National University, — Parametric resonance is a very interesting and important mechanism in divergent systems. There were a lot of researches relating to the parametric excitation in the magneto-optical trap system. However, the previous works were executed by modulating the cooling laser.
Classical chaos in a novel inhomogeneous photonic billiard

G. PAINCHAUD-APRIL, J. POIRIER, P.-Y. ST-LOUIS, J. LÉPINE, Université Laval, L. J. DUBE, Université Laval - Université du Québec à Montréal, Université du Québec à Chicoutimi

We introduce a new class of open optical microcavities whose confinement and directional emission properties can be engineered through modification of a space-dependent refractive index. Numerical results are provided for a microdisc with Gaussian deformation of the refractive index. This leads to a new way of breaking integrability and inducing chaos in the classically equivalent system (photonic billiard, see companion contribution in Category 7.3) and to the potential fabrication of reconfigurable microcavities.

ELECTRON-ATOM AND ELECTRON-MOLECULE COLLISIONS

MURTHADHA A. KHAKOO, California State University Fullerton CA 92834, S. WANG, California State University Fullerton, CA 92834

We study the consequences of this choice, isolate the conditions for integrability in such systems, describe the transition to chaos and classify the effects of the symmetry of the inhomogeneous dielectric on the trajectories.

Temperature Dependent Studies of Negative Ion Lifetimes

M. CANNON, Y. LIU, L. SUESS, F.B. DUNNING, Rice University, J. STEILL, R.N. COMPTON, University of Tennessee

The implementation of a powerful, accurate and novel method to measure elastic differential scattering cross sections (DCS) from gaseous targets, without having to know the molecular diameters of the gases used, will be presented. This is possible by taking advantage of the cosine angular distribution of gas produced by a thin aperture source. Preliminary tests with NO and CH₄ and other polyatomics will be presented at the meeting.

Temperature dependent studies of negative ion lifetimes

M. CANNON, Y. LIU, L. SUESS, F.B. DUNNING, Rice University, J. STEILL, R.N. COMPTON, University of Tennessee

The lifetimes of SF₆⁻ ions produced in K(nγ)/SF₆ collisions at high n are being investigated as a function of target temperature over the range 300K to 600K. At room temperature, collisions are found to lead predominantly to the formation of long-lived SF₆⁻ ions with lifetimes τ > 1ms. As the target temperature is raised long-lived (τ > 0.5ms) ions are still observed but their mean lifetime is reduced. In addition, the growth of a short-lived ion signal (τ < 0.1μs) is evident which, by 600K, accounts for ~45% of the total SF₆⁻ ion signal. These lifetimes are compared with those obtained using quasi-equilibrium theory and calculated SF₆⁻ vibrational frequencies. Measurement and theory are being extended to other attaching targets to further examine the factors that govern negative ion lifetimes.

Low energy electron scattering from N₂H molecules

BRENDAN M. MCLAUGHLIN, School of Mathematics and Physics, QUB, ROBERT C. FORREY, Department of Physics, Pennsylvania State University at Berks

Electron collisions with the N₂H anion N₂⁺ is an important constituent of understanding electron detachment in low energy H⁺ + N₂ collisions. Potential energy curves for both the neutral N₂H and anion N₂H⁻ molecules are calculated in C₃v symmetry for perpendicular, colinear and bent geometry using valence-CI and CASSCF approximations. Low energy electron scattering from the N₂H molecule are carried out using the R-matrix approach to determine the elastic scattering cross-section as a function of the colliding electron energy. Resonance energies and the autoionization linewidth (Γ) are determined in the elastic scattering cross sections are determined as a function of the stretching of the N₂ ↔ H bond length, where the N₂ molecule is fixed at its equilibrium geometry. A complex potential is then constructed from the resonance parameters and used in the heavy particle dynamical calculations to determine the low energy electron detachment cross sections and rates. Results for isotopic replacement of H⁺ by D⁺ have also been obtained for this cold molecular complex. Further details will be presented at the meeting.

Resonant positron annihilation in rings and substituted alkanes

J.A. YOUNG, C.M. SURKO, University of California, San Diego — Energy-resolved positron-on-molecule annihilation rates have been measured for a variety of molecules by passing a cold positron beam through test gases [1,2]. In many cases, the annihilation rates exceed the free electron annihilation rate by orders of magnitude. In particular, when the positron energy equals a vibrational mode energy minus the binding energy, large vibrational Feshbach resonances (VFR) are observed. In alkane molecules, the height of the C-H stretch resonances grow exponentially and the binding energy grows linearly with the number of carbons [1]. In this paper, we report new results for benzene, d-benzene, and 1-chlorohexane. Specifically, we examine the relationship between binding, C-H peak height, and molecular size. All these molecules have deeper binding than alkanes with similar numbers of carbons or atoms. An empirical trend will be discussed such that molecules with the same number of atoms have similar C-H peak heights when the simple kinematic effects of the binding energy on VFR are normalized out.


This work is supported by NSF, grant PHY 02-44653.
R1.00103 Resonant positron annihilation in the small molecule limit. C.M. SURKO, J.A. YOUNG, University of California, San Diego — Energy-resolved measurements of positron-on-molecule annihilation have established the existence of vibrational Feshbach resonances (VFR) in alkanes and other large molecules [1,2]. Large annihilation rates occur whenever the incident positron energy is close to a vibrational mode energy minus the binding energy. Recently, Gribakin and Lee developed a quantitative model which successfully describes this process in halogen substituted methanes [3]. In this paper, we further examine VFR for small molecules. Using a cold positron beam from a Penning-Malmberg trap, we measured the energy resolved annihilation spectra of CD$_3$Cl [3]. In this paper, we further examine VFR for small molecules. Using a cold positron beam from a Penning-Malmberg trap, we measured the energy resolved annihilation spectra of CD$_3$Cl. Since both should have identical binding, this provides a stringent test of the model. 


This work is supported by NSF, grant PHY 02-44653.

R1.00104 Modified COLTRIMS Technique to Measure Electron Interactions with Atoms and Molecules. J.B. WILLIAMS, J. STEWART, A. BHANDARY, E.J. CLOTHAUX, A.L. LANDERS, Auburn University, Auburn, AL 36849 — We have built a modified COLTRIMS apparatus to measure electron collisions with atoms and molecules. A beam from a pulsed electron gun passes through a diffuse target, followed by a synchronized electric field pulse which extracts the ions to a multi-channel plate detector with delay-line anode. By measuring positions and times of the extracted ions, relative cross sections differential in ion momentum can be determined. For example, this information can lead to both molecule orientation and dissociation energy. Preliminary results will be presented.

R1.00105 A Simple Method to Calculate Elastic Scattering of Electrons by Molecules of any Size. M. CRAWTREE, D. MADISON, University of Missouri-Rolla — We have developed a simple method to calculate differential cross sections for elastic scattering of electrons from molecules. The computer program called General Atomic and Molecular Structure System, or GAMESS, is used to generate molecular charge densities. The charge densities are used to calculate spherically averaged static potentials for an external electron. To the static potential, we add approximate correlation, polarization and exchange potentials. The resulting molecular potential is then used to calculate L-dependent phase shifts and elastic scattering cross sections. The accuracy of this simple method will be examined by comparing theoretical results with absolute differential cross section measurements that have been made for several different molecules.

This work supported by NSF grant PHY-0456528.


R1.00107 Implications for Atomic Physics from New Ionization Balance Calculations and Solar Physics Observations. PAUL BRYANS, Columbia Astrophysics Laboratory, ENRICO LANDI, Naval Research Laboratory, DANIEL SAVIN, Columbia Astrophysics Laboratory — We have used state-of-the-art electron-ion recombination data for K-shell, L-shell, and Na-like ions of H through Zn to calculate improved collisional ionization equilibrium (CIE) fractional abundances for ions of all these elements. We present the implications of these new CIE results for observations of the solar atmosphere and discuss a number of atomic systems showing puzzling discrepancies between observations and solar models. These discrepancies suggest errors in the underlying atomic data. Based on this, we highlight those atomic processes that require improved theoretical or experimentally-derived rate coefficients.

This work is supported in part by NASA.

R1.00108 Out-of-plane (e, 2e) experiments on helium autoionizing states. B.A. DEHARAK, N.L.S. MARTIN, University of Kentucky — Recent COLTRIMS experiments on charged particle ionization have found substantial disagreement with theoretical predictions. In particular the angular distribution of electrons ejected into a plane perpendicular to the scattering plane disagreed with expectations by a factor of between three and five. A mechanism has been proposed to explain these results that invokes a second collision of the projectile in which it undergoes elastic scattering with the residual ion. We are investigating such phenomena when autoionization is present: the finite lifetime of the intermediate state will profoundly affect any such second collision and will influence the ejected electron angular distributions. Our experiments are being carried out on an existing (e, 2e) apparatus modified to allow the electron gun to move on the surface of a (mathematical) cone. This permits the measurement of out-of-plane (e, 2e) angular distributions, for a full 360°, using a special geometry that allows out-of-plane conditions to be combined with the binary peak in a single measurement. Details of the apparatus, and the results of preliminary experiments on He 2s2p 1P, will be presented.

This work was supported by the United States National Science Foundation under Grant No. PHY-0555441.
R1.00109 Electron Impact Ionization of Noble Gas Atoms. RUDU CAMPEANU, York University — Electron impact single ionization of light noble gas atoms remains a formidable theoretical and computational challenge. Most experiments measuring total ionization cross sections are in agreement with each other, but on the theory side work is still needed for atoms heavier than helium. Distorted wave calculations, distorted-wave-R-matrix hybrid models, time-dependent close coupling calculations and coupled-channel-optical calculations produced total ionization cross sections which are in general significantly higher than the experimental data. Recent theoretical work on positron impact ionization of atoms and molecules was based on the use of several simple distorted-wave models. In these models the initial state of the atoms were represented in the Hartree-Fock approximation, while the incident and scattered positron and the ejected electron were described in a number of ways which tried to reproduce the pre and post-collision effects. We found that the inclusion in the final state representation of the electrostatic interaction between the ejected electron and scattered positron (model CPE4) produced good agreement with experiment for hydrogen and all the noble gases. In this paper we examine the possibility of employing electron impact ionization distorted-wave models similar to those successfully used in the positron impact ionization case. We find that when combined with the ‘maximum interference’ model, these models produce good agreement with the experiments.

1This work was supported by a NSERC grant.

R1.00110 Electron impact excitation of calcium. OLEG ZATZARINNY, KLAUS BARTSCHAT, Drake University, VICTOR GEDeon, LUDMILA BANDURINA, Ushgorod State University (Ukraine) — We have used the R-spline R-matrix (close-coupling) method with non-orthogonal sets of orbitals [1] to extend our recent calculation for low-energy elastic electron collisions with calcium atoms [2] to excitation of the lowest few excited states. Our results for state-selected angle-integrated and angle-differential cross sections, as well as angle-differential electron-impact correlation parameters, measured in electron-photon coincidence or superelastic scattering setups, will be compared with recent experimental data [3,4] and predictions from other theoretical methods [5,6].


1This work is supported, in part, by the United States National Science Foundation under grants PHY-0244470 and PHY-0555226.

R1.00111 A Study of Bremsstrahlung Produced From Solid Gold Films. SCOTT WILLIAMS, C.A. QUARLES, Texas Christian University — We report the results of our on-going study of the thickness-dependence of bremsstrahlung from solid gold film targets. The incident electrons’ energy is approximately 53 keV, and we have collected data from angles of 90 and 135 degrees. Target thicknesses ranging from 66 µg/cm² to 270 µg/cm² were used. (Where single interaction conditions apply) to more than twice the electron range (where a multiple interaction model applies) were studied. With this data, we can observe the transition from thin to thick film spectra, and compare it to data obtained using the Monte Carlo simulation, PENEOLE. This comparison could reveal whether there is any polarizational bremsstrahlung contribution for solid film targets. We also present results for the absolute doubly-differential cross section for the thin-film targets and compare the results with predictions of both ordinary bremsstrahlung and total bremsstrahlung including a polarization contribution calculated in the stripping approximation.

R1.00112 A Scaling for Differential Single and Multiple Ionization of Kr by Electron Impact. O.G. DE LUCIO, J. GAVIN, R.D. DUBOIS, University of Missouri-Rolla, Rolla, MO 65409 — Differential measurements of Kr ionization by electron impact were performed for an electron beam of 240 eV and 500 eV energies, colliding with a Kr gas jet target. Results for absolute doubly differential cross sections (DCSs) of Kr⁺, Kr²⁺ and Kr³⁺ ionization states are presented. Kr ions are pulled out of the interaction region by means of a pulsed field and recorded by means of a channeltron detector used in coincidence with a projectile detector in order to acquire differential information. DDCS plotted as a function of projectile energy loss and momentum transfer were investigated, some similarities were observed but in general no “universal curves” were found. By using a “reduced momentum” the DDCS for different angles, energy losses and even for different projectile energies could be compressed into two curves, corresponding to large (θ > 30°) and small (θ < 30°) scattering angles. These different scalings and variables will be presented and discussed.

R1.00113 Inner-shell Ionization With Relativistic Corrections By Electron Impact. BIDHAN SAHA, Department of Physics, Florida A&M University, FL-32307., M.A.R. PATOARY, M. ALFAZ UDDIN, A.K.F. HAQUE, ARUN K. BASAK, Department of Physics, Rajshahi University, Rajshahi, Bangladesh — A simple method is proposed and tested by evaluating the electron impact inner-shell ionization cross sections of several targets up to ultra high energy region. In this energy region there are not many calculations due to lack of reliable method. In this work we extend and modify the validity of the sBED model [1] in terms of targets and incident energies. The extension of our earlier RQIBED model [2] is also reported here and we examined its findings for the description of the experimental EICS data of various targets up to E=1000 MeV. Details will be presented at the meeting.


1BCS gratefully acknowledges the support from NSF CREST (grant 0630370).

R1.00114 An Attempt to Observe Mott Scattering Optically in Krypton. J.W. MASEBERG, T.J. GAY, University of Nebraska — We present recent measurements of the relative Stokes parameters for the 811 nm Kr (4p⁵5p)[5/2] → →(4p⁵5s)[3/2] |⁡p₂ transition excited by polarized electron impact. Of particular interest is the spin-normalized linear polarization fraction P_L. The upper excited state is well LS-coupled, a near-threshold observable non-zero value of P_L implies spin-orbit coupling between the target and continuum electron (an optical analog of Mott scattering) [1]. This work is a continuation of a previous paper wherein a cascade free measured P_L of 0.028(26) is compared to a theoretical 31-state Breit-Pauli R-matrix calculation which predicts a value of 0.032 [2]. Thus our earlier data is consistent with both the theory and zero. Our current effort is to increase the precision of these measurements.


1Supported by NSF Grant PHY-0354946.
R1.00115 Elastic Electron Scattering from the 6P and 5D Levels of Ba — JEFF HEIN, PETER ZETNER, University of Manitoba — Measurements of elastic electron scattering from excited atoms are relatively scarce and, hence, the ability to test theoretical descriptions of such a scattering process is rather limited. Here, we present experimental data for the differential cross section (DCS) and the P$_3$ Stokes parameter for elastic scattering from the 6P and 5D levels of Ba at collision energies of 10 and 20 eV. The P$_3$ parameter quantifies the dependence of elastic scattering on the orientation of the atomic target state. Oriented target states (5D and 6P) are produced using circularly polarized light to prepare the excited atoms. The present measurements extend the work of Trajmar et al.$^3$ undertaken with aligned Ba 6P atoms prepared by linear polarized laser light. Excellent agreement with conventional close coupling theory$^{2,3}$ has been found for the DCS. Significant orientation dependence of elastic scattering has been observed but agreement with theory is less satisfactory. 1. S. Trajmar et al. J. Phys. B: At. Mol. Opt. Phys. 32 2801 (1999) 2. I. Bray et al. J. Phys. B: At. Mol. Opt. Phys. 35 R117 (2002) 3. D. Fursa Private communication (2006)


R1.00117 Elastic Differential and Integral Elastic Cross Sections for e$^-$-Fr, Z. FELFLI, Clark Atlanta University, D. SOKOLOVSKI, Queen’s University of Belfast.UK, A.Z. MSEZANE, Clark Atlanta University, FELFLI/MSEZANE TEAM, SOKOLOVSKI COLLABORATION — Since an integral cross section is obtained by summing a partial wave series, singularities of the scattering matrix in the complex plane of the total angular momentum (Regge poles) are instrumental in understanding resonance effects in elastic, inelastic and reactive collisions. Typically, a resonance would not affect the energy dependence of an integral cross section $\sigma(E)$ if its angular life is much shorter than one full rotation of the metastable complex. In the opposite limit, a resonance would manifest itself as a sharp Breit-Wigner peak in $\sigma(E)$. We illustrate this on the Thomas-Fermi model foe e$^-$-Fr scattering[1]. Specifically, elastic partial and integral cross sections are investigated in the near threshold energy regime to understand the mechanism of electron attachment and predict new manifestations. We benchmark our approach by comparing the calculated results with those from the recent Dirac R-matrix method[2]. Results will be presented that highlight the existence of a shape resonance at $E = 0.334$ eV, in agreement with the Bahrim et al. results. Interestingly, a new sharp f-resonance appears at $E = 0.354$ eV and a p-wave Wigner threshold behaviour is identified. The general agreement with the Dirac R-matrix results gives credence to our simple approach. 1. Z. Felli et al., J. Phys. B 39, L53 (2006) 2. C. Bahrim et al., Phys. Rev. A 63, 042710 (2001)


$^1$Supported by U.S. DoE, Division of Chemical Sciences, Office of Basic Energy Sciences, Office of Energy Research.

R1.00119 A Fully Relativistic Approach for Calculating the Top-Up Contribution to Electron-Impact Excitation Cross Sections for Transitions between Magnetic Sublevels — CHRISTOPHER J. FONTES, HONG LIN ZHANG, Los Alamos National Laboratory — Previous work on relativistic electron-impact excitation calculations has been expanded to include transitions between magnetic sublevels. Specifically, a general expression has been derived for the relativistic plane-wave-Born (RPWB) cross section for electron-electron impact excitation between magnetic sublevels. This expression provides a convenient, accurate mechanism for estimating the high-$\ell$ partial-wave (or top-up) contribution to the corresponding relativistic distorted-wave (RDW) cross sections. This approach offers significant advantages over previous attempts to approximate the top-up contribution for RDW cross sections. For example, the RPWB top-up is fully relativistic and incorporates the correct kinematic description for relativistic collisions. Also, the RPWB approach is completely general in that it is applicable to any type of transition, while previous attempts employed the relativistic Coulomb-Bethe (RCB) approximation, which is valid only for dipole-allowed transitions. Another issue is that the RCB approach often converges slowly for $\Delta n = 0$ transitions, while the RPWB approach always produces a converged result because it includes contributions from $\ell \neq 0$ partial waves. Numerical examples will also be provided. This work was performed under the auspices of the US Department of Energy.

R1.00120 POST-DEADLINE —

R1.00121 An investigation of resonance involvement in electron circular dichroism of NMR shift reagent molecules$^1$, ADAM SCHEER, GORDON GALLUP, TIMOTHY GAY — We have measured the total scattering cross sections of several NMR shift reagent molecules, $X(hf)\sigma$, where $X =$ Yb, Er, Eu and Pr by means of electron transmission spectrometry (ETS) to determine their vertical attachment energies (VAEs). With the aid of restricted open-shell Hartree-Fock (ROHF) calculations on closely related molecules, we have assigned specific normally unoccupied orbitals to the resonances observed in ETS. Nolting et al. [J. Phys. B 30, 5491 (1997)] have demonstrated that the NMR shift reagents exhibit electron circular dichroism (ECD) between 1-10 eV. We reexamine their asymmetry spectra and provide a set of possible orbital assignments for major ECD structures. Inconsistencies in associating asymmetry features with resonances observed in the total scattering cross section are also discussed. Specifically, significant shifts to lower energy are observed in analogous ECD features as the atomic number of the central lanthanide atom decreases. However, similar shifts in VAEs are not seen as would be expected if resonance behavior were solely responsible for asymmetry.

$^1$This work was supported by the NSF under grant PHY-0354946.
R1.00122 Extensive computation of allowed and forbidden transition probabilities in the potassium isoelectronic sequence, GOPAL DIXIT, PRANAWA C. DESHMUKH, IIT Madras, STEVEN T. MANSON, Georgia State University, SONJOY MAIJUMDER, IIT Madras — Our primary aim in this work is to present both allowed and forbidden transition amplitudes and corresponding wave-lengths and oscillator strengths for a few ions in the 19-electron potassium isoelectronic sequence. All of these ions have the configuration [Ar] 3d^2S_{1/2} as their ground state, except in the case of K and Ca^+; where it is [Ar] 4d^2S_{1/2}. This difference in ground state configuration arises due to strong contributions of correlation effects in the energy levels of these systems [1]. Allowed and forbidden transitions in these systems are of great importance in astrophysics [2] and in laboratory plasma research [3]. We apply in the present work the relativistic coupled-cluster (RCC) theory [4] to evaluate the energy levels and wave functions of these systems and study amplitudes for electric and magnetic dipole transition amplitudes and also the electric quadrupole transition amplitudes. The contributions of various electron correlation effects to the transition amplitudes are estimated in some detail using the RCC theory. [1] Gopal Dixit et al., Astrophys. J (submitted); arXiv.org: physics/0702066. [2] C. R. Cowley and G. M. Wahlgren, Astronomy & Astrophysics, 447, 681 (2002). [3] J. E. Vernazza, E. M. Reeves, Astrophys. J. Suppl. 37, 485 (1978) [4] I. Lindgren, Physics Scripta, 36, 591 (1987).

R1.00123 Quantum Process Tomography, KAVAN MODI, CESAR RODRIGUEZ, AIK-MENG KUAH, GEORGE SUDARSHAN, The University of Texas at Austin, ANIL SHAJI, Univ. of New Mexico at Albuquerque — Quantum process tomography has become a very important tool in quantum information science. It is the way to study the detailed structure of a quantum channel. We will examine some recent experiment on quantum process tomography. We will point out some ambiguity in the way these experiments were performed. We will show how these ambiguities lead to incorrect conclusion, namely the “unphysical” result of not completely positive map. The notion that a dynamical map must be completely positive is erroneous. We will present specific examples in which this is not the case. We will also present a recipe that will resolve any ambiguity in the future.

R1.00124 Electron-impact ionization rates for BF_3 fragments, L. VUSKOVIC, M. RASKOVIC, S. POPOVIC, Old Dominion University, Norfolk VA — We calculated electron-impact ionization rates of BF_3 and its fragments for electron energy distribution present in sheath mode of the repetitively pulsed d.c. diode system [1]. Data are being used for Ar/BF_3 discharge modeling. BF_3 and its fragments are reactive species that we are using to interact with niobium surface which is the aim to remove oxides and other impurities from the surface in the form of volatile compounds. This procedure of cleaning and smoothening improves the performance of the superconducting radiofrequency cavities used for particle accelerators. In our calculation electronic structures of BF_3 and its fragments were described with several empirical basis sets. After geometry optimization using density functional method B3LYP, MO parameters were calculated with UHF, CCSD(T) and OVGF methods [2]. Electron-impact ionization cross-sections were calculated employing the Binary-Encounter-Bethe approximation. Cross-section results were compared with available experimental data. Relative calculation errors were estimated, which was especially important for cross-sections obtained with CEP-31G basis set that is necessary to describe system containing niobium samples. [1] S. Radovanov et al., J. Appl. Phys. 98, 113307 (2005). [2] Y.-K. Kim, K.K. Irikura, AIP conferences proceedings, 543, 220 (2000).

1Supported by DOE

R1.00125 Correlation Functions and Multiparticle Entanglement in Cavity QED, PERRY RICE, JAMES CLEMENS, Miami University, LUIS OROZCO, University of Maryland — Entanglement is essentially a quantum correlation between two systems, as such a cross-correlation function can be shown to indicate entanglement between two parts of a system. If the state of the system is a product state, with no entanglement, then the correlation function is unity. If any cross-correlation of the form above is not equal to one, then the two modes are entangled. Here we consider a multi-level atom, and two orthogonal polarization modes of the cavity. The atom is driven with polarization a. The atom can spontaneously emit either the a mode, or the b mode. As the b mode is undriven, light of that polarization can only arise from spontaneous emission. Hence perhaps one can measure the entanglement between the atom and field mode by a cross-correlation of the two modes a and b. The problem with this is that we now have an atom and two field modes, and hence a tripartite system. In such systems, measures of entanglement are not well defined. Here we examine the use of correlation functions to discuss entanglement in this system. Work supported by NSF, NIST, and Research Corporation.

R1.00126 Steering, Entanglement, Nonlocality, and the EPR Paradox, HOWARD WISEMANN, STEVE JONES, Centre for Quantum Dynamics, Griffith University, DOHERTY ANDREW, University of Queensland — The concept of steering was introduced by Schroedinger in 1935 as a generalization of the EPR paradox for arbitrary pure bipartite entangled states and arbitrary measurements by one party. Until now, it has never been rigorously defined, so it has not been known (for example) what mixed states are steerable (that is, can be used to exhibit steering). We provide an operational definition, from which we prove (by considering Werner states and Isotropic states) that steerable states are a strict subset of the entangled states, and a strict superset of the states that can exhibit Bell-nonlocality. For arbitrary bipartite Gaussian states we derive a linear matrix inequality that decides an operational definition, from which we prove (by considering Werner states and Isotropic states) that steerable states are a strict subset of the entangled states, and a strict superset of the states that can exhibit Bell-nonlocality. For arbitrary bipartite Gaussian states we derive a linear matrix inequality that decides the question of steerability via Gaussian measurements, and we relate this to the original EPR paradox.

1Supported by the Centre for Quantum Computer Technology of the Australian Research Council

R1.00127 Conditioned Homodyne Measurements and Entanglement for a Two-Level Atom in an OPO, PERRY RICE, Miami University, JEFFREY HYDE — It has been shown that entanglement between a two-level atom and a field mode can be characterized by correlations between transmitted and fluorescent light. A particularly useful quantity is the cross-correlation function h_{\phi\phi}^{FT}(0), a conditioned homodyne measurement of the transmitted field, conditioned on the detection of a fluorescent photon. Obviously it would be better to create the photons in pairs via a parametric process. A two-level atom in an optical parametric oscillator has been shown to have nonclassical spectra and photon statistics and be useful for teleportation and single photon storage. Here we demonstrate that various cross-correlation functions are an indication of entanglement, and that the conditioned homodyne measurement is an actual measure of entanglement. Work supported by NSF, NIST, and Research Corporation.

R1.00128 ABSTRACT WITHDRAWN —

R1.00129 Decay width of negative positronium ion, MARIUSZ PUCHALSKI, ANDRZEJ CZARNECKI, University of Alberta, Edmonton, SAVELY KARSHENBOIM, Max Planck Inst. Quantenopt., Munich — We present a precise theoretical prediction for the decay width of the bound state of two electrons and a positron (a negative positronium ion). We include O(\alpha^2) effects of hard virtual photons as well as soft corrections to the wave function and the decay amplitude. An outcome of a large-scale variational calculation, this is the first result for second-order corrections to a decay of a three-particle bound state. It will be tested experimentally in the new positronium-ion beam facility in Garching in Germany.
R1.00130 Quantum Interferometry at the Heisenberg Limit. LUCA PEZZE', AUGUSTO SMERZI, BEC-CNR-INFM and Dipartimento di Fisica, Università di Trento, I-38050 Povo, Italy — Entanglement can increase the precision of an interferometric phase measurement from the standard quantum limit up to the Heisenberg limit, which is the ultimate bound imposed by Quantum Mechanics. The quest requires two key ingredients: maximal quantum correlations engineered among the particles employed in the measurement process and a tailored phase estimation strategy. Here we present a rigorous Bayesian protocol for unbiased estimation of phases with confidence at the Heisenberg limit which overcomes basic difficulties present in previous approaches. We also demonstrate phase sensitivity beating the classical shot-noise limit with published experimental probabilities for Schroedinger cats up to N=6 beryllium ions. We report 0.8 db sub shot-noise implemented with an arbitrary large number of particles and maximum priori ignorance. Possible implementation of the protocol with trapped Bose-Einstein condensates will also be discussed.

R1.00131 Optimal phase estimation for a Mach-Zehnder interferometer. LUCA PEZZE', AUGUSTO SMERZI, BEC-CNR-INFM and Dipartimento di Fisica, Università di Trento, I-38050 Povo, Italy; GEORGE KHOURY, JUAN HOEDLIN, DIRK BOUWMEESTER, Department of Physics, University of California, Santa Barbara, California 93106, USA — We study a Mach-Zehnder interferometer fed by a coherent state in one input port and vacuum in the other. We explore a Bayesian phase estimation strategy to demonstrate that is possible to achieve the standard quantum limit independently from the true value of the phase shift and specific assumptions on the noise of the interferometer. We have been able to implement the protocol using parallel operation of two photon-number-resolving detectors and multiphoton coincidence logic electronics at the output ports of a weakly-illuminated Mach-Zehnder interferometer. This protocol is unbiased and saturates the Cramer-Rao phase uncertainty bound and, therefore, is an optimal phase estimation strategy.

R1.00132 Reduced Density Matrix Descriptions for Electromagnetically Induced Transparency in Atomic Systems. VERNE JACOBS, Naval Research Laboratory — Reduced density matrix descriptions are developed for electromagnetically induced transparency and related pump-probe optical phenomena in moving atomic systems, taking into account atomic collisions and external magnetic fields. Time-domain (equation-of-motion) and frequency-domain (resolvent-operator) formulations are developed in a unified manner. In a preliminary semiclassical perturbative treatment of the electromagnetic interaction, compact Liouville-space operator expressions are derived for the linear and the general (n'th order) non-linear electromagnetic-response tensors. These expressions are valid for coherent atomic excitations and for the full tetradic-matrix form of the collision operator in the Markov approximation.

1Work supported by the Office of Naval Research and the Defense Advanced Research Projects Agency.

R1.00133 Evidence of Electron Spin-Dependent Terahertz Light Transport in Spintronic-Plasmonic Media. KENNETH CHAI, University of Alberta, MARK JOHNSON, Naval Research Laboratory, ABDULHAKEM ELEZZABI, University of Alberta — Plasmonics and spintronics are actively pursued as means to sustain the continued miniaturization of information technology. Combining the advantages of both technologies could potentially pave the way for the development of highly integrated light-based devices. Here, we provide evidence of a new spin-dependent plasmonic phenomenon. Using a rudimentary plasmonic circuit, namely, a dense ensemble of ferromagnetic/nonmagnetic (F/N) metallic microparticles, we demonstrate that electron spin can influence terahertz plasmonic transport across the particles. In particular, by coating the ferromagnetic Co particles with nonmagnetic Au nano-layers, the terahertz transmission shows large magnetic field-dependent attenuation, enhanced relative to that of pure, uncoated Co particles. We show that enhanced magnetic attenuation in the F/N particles arises from dynamic spin accumulation in the nonmagnet. A quantitative measurement of the dependence of the attenuation on the N layer thickness is in good agreement with the spin diffusion length predicted by the spin accumulation model, as well as with other measurements of this length. The discovery may potentially lead to plasmonic devices operating in the visible regime that exploit electron spin.

R1.00134 An Offset-Apertured Near-Field Scanning Optical Microscope Probe. MICHAEL QUONG, ABDULHAKEM ELEZZABI, University of Alberta — A novel hybrid apertured and scattering-type (“hybrid”) near-field scanning optical microscope (NSOM) probe design in the form of a cantilevered offset-apertured probe is presented. In the cantilever arm, a subwavelength aperture is located adjacent to the base of a metal-coated dielectric tip. Surface plasmon waves are coupled onto the tip’s surface. The surface plasmon waves propagate to the tip’s apex, where the fields are locally enhanced. As a result of the offset-apertured probe design, the low light throughput of typical apertured NSOMs and the background light-related problems of scattering-type NSOMs are circumvented. Unlike other hybrid NSOM probe designs, the offset-apertured probe’s sharp apex allows for optical imaging in deep and narrow topographical features. To gain greater insight into the functioning of the offset-apertured probe, the dependences of the optical spot’s intensity and full-width half-maximum on various geometrical parameters are characterized through numerical calculations. Results also demonstrate that an offset-apertured probe significantly improves throughput light intensity over a typical apertured NSOM probe having similar resolution.

R1.00135 Large-Angle Deflection of MOT-Based Cold Cs Beam by Optical Molasses. H. WANG1, G. IYANU, The Aerospace Corporation — We have generated a slow moving Cs atomic beam from a vapor-cell Cs MOT and deflected the cold Cs beam by an angle of 30 degrees using a 1-D optical molasses. The MOT-generated Cs atomic beam travels at a mean velocity of 7 m/s with a velocity spread of 1 m/s. At 18 cm down-stream from the Cs MOT, the Cs atomic beam interacts with a 1-D optical molasses formed by a pair of frequency-stabilized, retro-reflected laser beams. The 1-D optical molasses is set up in such a way that the molasses laser beams are perpendicular to the final atomic beam propagation path. Thus, the Cs beam velocity components along the molasses axes are efficiently damped to nearly zero, while the velocity component along the final atomic beam propagation path is unaffected. In a probe region about 34 cm down-stream from the optical molasses, laser induced fluorescence of the deflected Cs beam is obtained and used for studies of the atomic beam deflection efficiencies and beam manipulation parameters. This deflected Cs atomic beam will be used in our cold Cs beam atomic clock experiment. This work was supported under The Aerospace Corporation’s Mission Oriented Investigation and Experimentation program, funded by the U.S. Air Force Space and Missile Systems Center under Contract No. FA8802-04-C-0001.

1he.wang@aero.org

R1.00136 Transfer of Ultracold 87Rb from a QUIC Magnetic Trap into a Far Off Resonance Optical Trap. MING HE, WILLIAM A. VAN WUNGAARDEN, York University — Ultracold 87Rb atoms were transferred from a QUIC magnetic trap into a far off resonance optical trap (FORT). FORTs were created by focusing a 150 mW laser beam having a wavelength of 852 nm to a spot having a radius of 20 and 30 μm. A probe laser then passed through the ultracold atom cloud after the magnetic trap was turned off to study the temporal evolution of the optically trapped atoms. Nearly a million atoms could be transferred into the FORT at temperatures as low as 1 μK with an efficiency as high as 50%.

R1.00137 Nanoscale Resolution Fluorescence Using Cold Atoms. DENIZ YAVUZ, NICHOLAS PROITE, University of Wisconsin - Madison — We suggest a new type of scanning fluorescence microscope that is capable of resolving nanometer size objects in the far field. The key idea is to use a position dependent Stark Shift of a Raman transition to produce atomic excitation tightly confined to nanometer spatial scales. We present numerical simulations that demonstrate a resolution that is 40 times smaller than the wavelength of light. We discuss in detail a possible first experiment where a nanoscale object is embedded in an ultracold atomic cloud and a high resolution image is obtained at the far field.
R1.00138 Coherent Raman spectroscopy with incoherent laser pulses, XIAOJI XU, STANISLAV KONOROV, JOHN HEPBURN, VALERY MILNER — Contrary to the common belief that noise and decoherence are detrimental to spectroscopic measurements, we propose and experimentally demonstrate a new method of coherent Raman spectroscopy with spectrally broad incoherent laser pulses. Laser induced molecular vibrations are probed by broadband laser pulses with intentionally introduced spectral phase noise. The vibrational resonances are identified through intensity correlations in the noisy spectrum of the scattered anti-Stokes photons. Spectral resolution is neither limited by the pulse bandwidth nor sensitive to the temporal profile quality of the pulses. The method does not require complicated pulse-shaping setups, spectral multiplexing or spatial beam arrangements. It enables full utilization of the broad bandwidth of femtosecond pulses, and quick scanless retrieval of the vibrational beating frequencies.

R1.00139 Adiabatic passage with ultrashort laser pulses, SERGEY ZHDANOVICH, EVGENY SHAPIRO, CIAN MENZEL-JONES, MOSHE SHAPIRO, JOHN HEPBURN, VALERY MILNER — We develop a method of executing complete population transfer between quantum states using a series of femtosecond laser pulses. The method can be applied to a large class of problems as it benefits from the high peak power and large spectral bandwidth afforded by ultrashort pulses. The new type of “piecewise adiabaticity” is reflected by the robustness of the degree of population transfer to a wide variation in the intensities, durations, and time delays between the pulses. The method is studied in detail for two- and three-level systems, and demonstrated experimentally in atomic rubidium where piecewise adiabatic population transfer between two electronic states is observed. Piecewise adiabatic passage offers a new set of tools for manipulating the population of atomic and molecular states on ultrashort time scale.

R1.00140 Investigation of xenon metastable atoms, TIAN XIA, YUAN-YU JAU, WILLIAM HAPPER, Princeton University, HAPPER LAB TEAM — The electron configuration of a xenon atom in its metastable state consists of tightly bound core electrons with a single missing electron in the 5P shell, and a loosely bound “valence electron” in the 6S shell. For our current work, we have been using pyrex cells with internal tungsten electrodes, filled with isotopically enriched Xe129 gas. Ti-sapphire laser is used to pump the metastable atom from 6S2 to 6P2 and 6P3 at 823nm and 882nm respectively. The absorption spectrum is able to resolve the hyperfine structure of Xe129 in 6S2, 6P2 and 6P3 state. The hyperfine coefficients for 6S2, 6P2 agree with previously reported measurements. And the hyperfine coefficient for 6P3 state has not been reported before. If the pumping wavelength is locked at any one of the hyperfine transitions of Xe129 atom, zero-field magnetic resonances of metastable Xe129 atoms could be observed by pumping with circularly polarized laser beam. Since relaxation between magnetic sublevels is very fast due to the big depolarization collisional cross section, the linewidth of the magnetic resonant signal is broad.

1Investigation of xenon metastable atoms

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AND
Replace abstracts DAMOP07-2007-020094

(Had made a mistake in previous resubmission)

R1.00141 Soft x-ray driven femtosecond dynamics, ARVINDER S. SANDHU, JILA, University of Colorado at Boulder, Boulder Co 80309 — We present the first direct observation of molecular dynamics initiated by an EUV pulse. A novel EUV pump-IR probe technique is implemented. By measuring the vibrational beating frequencies, we infer the potential energy curves for the molecular states. As the internuclear distance increases, we observe a fast decrease in the kinetic energy, leading to the dissociation of the molecular state.

1Soft x-ray driven femtosecond dynamics of ionic Rydberg states in N2

R1.00142 Resonant Association of Feshbach Molecules, THOMAS M. HANNA, THORSTEN KOHLER, KEITH BURNETT, Clarendon Laboratory, Department of Physics, University of Oxford, Oxford, UK — In recent experiments, Feshbach molecules have been associated using resonant modulation of a magnetic field close to a zero-energy resonance [1, 2]. We analyse the dependence of this process upon the duration, amplitude and frequency of the modulation, as well as the temperature and density of the gas. A modulation of angular frequency $\omega$ resonantly couples a pair of atoms with relative kinetic energy $p^2/m = \hbar \omega - E^\text{av}$. The energy $E^\text{av}$ is the molecular bound state energy. The presence of a continuum of modes around this energy has a strong influence on the final conversion efficiency. Shifts in the modulation frequency giving maximum conversion are created by the amplitude of the modulation and the temperature of the gas. We discuss the importance of mean-field effects at short times, and predict that resonant association can be effective for binding energies of order $h \times 1 \text{ MHz}$.


R1.00143 An investigation of non-Brownian random walks in an optical lattice using polarization-selective intensity correlations, BENJAMIN AGYARE, SAMUEL BISH, MATTHEW BRIEL, SAMIR BALI, Department of Physics, Miami University, Oxford, OH 45056 — We propose that Levy walks by cold atoms trapped in a near-resonance shallow optical lattice may be probed by measuring the polarization-selective intensity correlations of the scattered light. Experimental progress is reported.

R1.00144 High resolution spectroscopy of Rydberg atom interactions, K.C. YOUNGE, A. REINHARD, P.R. BERMAN, G. RAITHEL, FOCUS Center and Department of Physics, University of Michigan — We present progress toward a direct spectroscopic measurement of the dipole-dipole and van der Waals interactions between Rydberg atoms excited from a cold gas. We have collected $^{85}\text{Rb}$ atoms in a broadband optical dipole trap (laser wavelength 1064nm) with a 15 micron FWHM diameter, and characterized the temperature, atom number, density, and size of the trapped sample using shadow imaging. The dipole trap will be employed to measure Rydberg-atom interactions using two independently tunable Rydberg excitation laser pulses. The first pulse is tuned to the interaction-free Rydberg excitation resonance; this pulse prepares a dilute gas of cold Rydberg atoms. The frequency of the second pulse is scanned relative to that of the first one, allowing us to map out the spectrum of energy-shifted collective states. In our poster, we will discuss methods and results, as well as potential applications in quantum information processing.

Work supported by: FOCUS and NSF Grant No. PHY-0555520.
R1.00145 Hyperfast time-resolved spectroscopy of electron correlation in excited states, CLEAN-THES A. NICOLAIDES, National Technical University, Athens, Greece — As a consequence of continuing developments in the science and technology of techniques that produce and control electromagnetic pulses with frequencies that are found in a broad part of the spectrum, from the infrared to the soft X-rays, it is possible to have hyperfast pump-probe time delay spectroscopic techniques capable of time resolving the dynamics of various atomic and molecular systems involving excited states. In this context, it has been demonstrated via first principles solution of the time-dependent Schrödinger equation (TDSE), that effects which are caused by strong electron correlations in excited states, including the process of autoionization and the formation of resonances, can be time-resolved on a time scale of attoseconds [1-3]. By extending the investigations to polyelectronic atoms, we have obtained new results for various time resolved processes associated with the photo-ejection of inner (2s) electrons and of two electrons (LM) from the thirteen electron atom of Aluminum and with the electron correlation beats in bound and autoionized states of N\textsuperscript{1-3} and Al. The theory and computations account for the interference of direct double ionization, inner hole states and Auger decay [4].


R1.00146 The Far-IR Beamlime at the Canadian Light Source. DOMINIQUE R.T. APPADOO, Canadian Light Source, Inc. — The far-infrared (far-IR) beamline at the Canadian Light Source Inc. (CLSI) has been dedicated primarily to high-resolution spectroscopic studies of stable and unstable gas-phase molecules. The infrared radiation collected from a Bending Magnet is steered using long wavelength optics to a Bruker IFS125HR spectrometer which is able to record spectra at a resolution of 0.001 cm\(^{-1}\). The far-IR beamline is presently being commissioned, and recent efforts in the optical alignment and noise reduction have rendered the beamline partially operational. The signal-to-noise ratio of data recorded with the synchrotron is better than that recorded with a thermal source by a factor of 8 around the 400 - 600 cm\(^{-1}\) region. As a result, we are presently accepting proposals for the next cycle (July - Dec 2007) for experiments which can be conducted in this spectral region.

R1.00147 KRb Feshbach Molecules. KANG-KUEN NI, J.J. ZIRBEL, S. OSPELKAUS, J. YE, S. JIN, University of Colorado — We have produced heteronuclear Feshbach molecules from an ultracold gas mixture of K40-Rb87 in an optical dipole trap. We can create more than 30,000 molecules at about 100 nK and we have observed molecule lifetimes as long as 20 ms near the Feshbach resonance. We will report on measurements of the Feshbach molecule lifetime as a function of magnetic-field detuning from resonance. These results are compared with theoretical predictions for vibrational quenching of heteronuclear Feshbach molecules.

Saturday, June 9, 2007 8:00AM - 10:36AM – Session W2 Focus Session: Slowing and Stopping Light TELUS Convention Centre Macleod D

8:00AM W2.00001 Towards single photon nonlinear optics with confined photons and atoms. MIKHAIL LUKIN, Physics Department, Harvard University — We will describe two novel approaches for realization of controlled, deterministic nonlinear optics at a single photon level. These approaches combine the ideas of Electromagnetically Induced Transparency and slow light with tight confinement of photons and atoms. Progress towards realization of these ideas will be discussed. Specifically, we will describe proof-of-principle experimental realization of strong coupling between individual CdSe quantum dots and surface plasmons localized on nano-sized conducting wire. In addition, progress towards realization of novel nonlinear optical medium based on ultra-cold atoms confined in a hollow photonic crystal fiber will be discussed. As an outlook we will discuss novel applications of these ideas. These include switching and transistors operating at a single photon as well as strongly interacting many-body physics with photons.

8:36AM W2.00002 Observation of Quantum Destructive Interference in Inelastic Two-Wave Mixing. L. DENG, National Institute for Standards and Technology — Using room-temperature \(^{87}\)Rb atoms we demonstrate a quantum destructive interference between two one-photon excitation pathways in an inelastic two-wave mixing scheme that corresponds to the “strong-storage and weak-retrieval” of an optical field. This destructive interference is fundamentally different from the usual electromagnetically-induced-transparency because it is critically dependent on the generation and propagation of a wave-mixing field. We also show that contrary to the common belief, that the maximum atomic coherence in general does not lead to the maximum mixing-wave conversion efficiency.

9:12AM W2.00003 Towards storage of squeezed light by electromagnetically induced transparency. JÜRGEN APPEL, University of Calgary, EDEN FIGUEROA, University of Calgary, FRANK VEWINGER, University of Bonn, DMITRY KRYSTOV, University of Calgary, GEORG GÜNTER, University of Konstanz, ALEXANDER LVOVSKY, University of Calgary — Electromagnetically induced transparency (EIT) is a quantum interference effect, in which a strong control laser beam changes a medium’s linear dispersion and absorption in such a way that a weak signal beam travels without absorption and its group velocity is greatly reduced. Theoretical models and recent experiments predict that adiabatic switching of the control field while the signal is inside the medium reversibly maps the signal quantum state to the states of the irradiated atoms. We report on our recent progress in storing and retrieving a squeezed optical state by adiabatic conversion to a collective coherent superposition of the hyperfine ground levels of the D1 transition in rubidium-87. A bright narrowband source of nonclassical light for interaction with atoms has been constructed based on an optical parametric amplifier featuring a periodically poled KTP crystal. Ultrafast lossless switching allows us to generate 1 μs pulses of up to 3 dB squeezed vacuum resonant to the EIT transparency window. We investigate the transmission and storage of these states under EIT conditions by homodyne tomography.

9:24AM W2.00004 Slow and stored light in paraffin-coated Rb vapor cells. MASON KLEIN, MICHAEL HOHENSEE, YANHONG XIAO, IRINA NOVIKOVA, DAVID PHILLIPS, RONALD WALSWORTH, Harvard-Smithsonian — The slow ground-state decoherence rate of paraffin-coated Rb vapor cells leads to a dual-structured electromagnetically induced transparency (EIT) spectrum with a narrow (<100 Hz) transparency peak on top of a broad pedestal. We present an experimental study of the effect of such dual-structured EIT on slow and stored light. Based on dynamical simulations we consider optimal conditions for storage and retrieval of optical information.

9:36AM W2.00005 Slow and Stored light optimization procedure. IRINA NOVIKOVA, College of William & Mary, ALEXEY V. GORSHKOV, Harvard University, DAVID F. PHILLIPS, Harvard-Smithsonian Center for Astrophysics, ANDERS S. SORENSEN, QUANTOP, Danish National Research Foundation Centre of Quantum Optics, MIKHAIL D. LUKIN, Harvard University, RONALD L. WALSWORTH, Harvard-Smithsonian Center for Astrophysics — Optimization of slow and stored light for high fidelity retrieval of input pulses requires tailoring of the input probe field shape or the applied control field used in the slow or stored light process. We present an experimental procedure for the optimization of probe and control field profiles in EIT-based stored light to achieve maximum storage and retrieval efficiency for a given optical depth. The details and limitation for application of this procedure in a Rb vapor cell are discussed.
Critical behavior of a trapped interacting Bose gas. STEPHAN RITTER, TOBIAS DONNER, THOMAS BOURDEL, FERDINAND BRENNENKE, ANTON ÖTTL, MICHAEL KÖHL, TILMAN ESSLINGER, Institute for Quantum Electronics, ETH Zurich, Switzerland — In the vicinity of a phase transition minute variations in the controlling parameters can dramatically change the properties of a system. Using a trapped Bose gas we have entered the critical regime of Bose-Einstein condensation and gained access to its beyond mean-field physics. This regime is characterized by fluctuations extending far beyond the thermal de Broglie wavelength: The length scale over which the system behaves coherently diverges, which is directly reflected in the shape of the spatial first order correlation function. Using matter-wave interference we measure the correlation length of the order parameter as the temperature approaches the critical point and determine its critical exponent for a trapped, weakly interacting Bose gas to be $\nu = 0.67 \pm 0.13$. The system exhibits the expected $\nu = 2/3$ correlation length scaling, which is a direct signature of the universality of Bose liquid physics.
9:12AM W4.00007 Observation of Faraday Waves in a Bose-Einstein Condensate, PETER ENGELS, COLLIN ATHERTON, Washington State University, Pullman, WA 99164, MARK HoeffeER, National Institute of Standards and Technology, Boulder, CO 80305 — Faraday waves in a cigar-shaped Bose-Einstein condensate are created. It is shown that periodically modulating the transverse confinement, and thus the nonlinear interactions in the BEC, excites small amplitude longitudinal oscillations through a parametric resonance. It is also demonstrated that even without the presence of a continuous drive, an initial transverse breathing mode excitation of the condensate leads to spontaneous pattern formation in the longitudinal direction. Finally, the effects of strongly driving the transverse breathing mode with large amplitude are investigated. In this case, impact-oscillator behavior and intriguing nonlinear dynamics, including the gradual emergence of multiple longitudinal modes, are observed.

9:24AM W4.00008 Chaotic escape dynamics of ultracold and Bose-condensed atoms, KEVIN MITCHELL, University of California, Merced, DANIEL A. STECK, Oregon Center for Optics and Department of Physics — We consider the nonlinear dynamics of small packets of ultra-cold and Bose-condensed atoms in a two-dimensional, double-well optical trap, composed of two overlapping Gaussian beams. We are interested in the transport of such packets from one side of the well to the other, and potential escape from the trap. We theoretically investigate how the time-dependent escape rate of atoms from the trap is influenced by the chaotic dynamics of the potential and by the inherent nonlinearity induced by atom-atom interactions.

9:36AM W4.00009 Modeling the Expansion of Bose–Einstein Condensate Mixtures in the Thomas–Fermi Limit, MARK EDWARDS, LAURA HALMO, CHARLES HOLCOMBE, Georgia Southern University — We have studied the expansion of a mixture of $^{85}\text{Rb–87}\text{Rb}$ Bose–Einstein condensates within the Thomas–Fermi approximation. Systems involving mixtures of Bose–Einstein condensates of different atomic species can be accurately modeled by coupled Gross–Pitaevskii equations. As for single condensates, the coupled Gross–Pitaevskii equations can be written in hydrodynamic form where each condensate is described by a density and phase. Also just as for single condensates, the hydrodynamic equations of motion for condensate mixtures reduce to classical equations of motion when their quantum pressure terms are neglected (Thomas–Fermi approximation). In this case, it is possible to find time–dependent Thomas–Fermi approximate solutions for the hydrodynamic equations of motion for mixtures. We present these equations and their solution for the particular case of a $^{85}\text{Rb–87}\text{Rb}$ expansion that occurred in a recent experiment performed in the Jin group at JILA. We also highlight interesting features that can occur because of interaction effects in the expansion of multiple–condensate mixtures.

9:48AM W4.00010 A Bose-Einstein Condensate Level, SATYAN BHONGALE, University of New Mexico, EDDY TIMMERMANS, Los Alamos National Laboratory — We consider a trapped, phase separated two-component or two-species Bose-Einstein condensate (BEC) system: a large BEC of bosonic atoms of type ’a’ in which a smaller bubble of a BEC of ’b’ atoms is immersed. If the trapping force of BEC a is tuned near the value at which it nearly cancels the buoyancy force experienced by the immersed BEC- b fluid, the equilibrium center-of-mass position of the BEC-b bubble becomes highly sensitive to any force difference experienced by the a and b atoms. Imaging the position of the BEC-b bubble than gives a sensitive measure of the external force. If the cancellation is nearly complete, the equilibrium position of the nearly freely floating BEC-b bubble can be used to study the Casimir-like forces generated by the quantum fluctuations of he finite size BEC-system.

10:00AM W4.00011 Calculation of $g_3$ for a Finite Temperature Gas, ALICE BEZETT, EMESI TOTH, BLAIR BLAKIE, Jack Dodd and Dan Walls Centre for Photonics and Ultra-Cold Atoms — The landmark experiment done by Hanbury-Brown and Twiss (HBT) in 1956 has seen a renewal of interest in application to ultra-cold gases. It has long been desired that the HBT effect, that is, correlations between photons from a thermal source, be verified for bosonic atoms from a thermal cloud. There is a prohibitively small probability of observing a many-particle correlation effect in a conventional particle beam, and for this reason laser cooling and a combination of laser and evaporative cooling are employed in studies of particle correlations. We present a finite temperature theoretical model for calculating correlations in degenerate Bose gas that systematically includes the effects of harmonic trap confinement, interactions between the particles and is valid in the critical regime. This model is based on the non-perturbative Projected Gross Pitaevskii (PGPE) formalism, which includes the dynamics of the low lying modes of the thermal cloud, coupled to a semiclassical description of high the energy modes. We discuss results of these simulations for a three dimensional cloud of ultra-cold bosons at a range of temperatures below $T_c$.

10:12AM W4.00012 Radial and angular rotons in trapped dipolar gases, SHAI RONEN, JILA and Department of Physics, University of Colorado, Boulder, CO-80309-0440, USA, DANIELE BORTOLOTTI, JILA and Department of Physics, University of Colorado, Boulder, CO, USA; LENS and Dipartimento di Fisica, Università di Firenze, Italy, JOHN BOHN, JILA, NIST, and Department of Physics, Boulder, CO 80309-0440, USA — We study Bose-Einstein condensates with purely dipolar interactions in oblate (pancake) traps. We find that the condensate always becomes unstable to collapse when the number of particles is sufficiently large. We analyze the instability, and find that it is the trapped-gas analogue of the “roton-maxon” of small packets of ultra-cold and Bose-condensed atoms in a two-dimensional, double-well optical trap, composed of two overlapping Gaussian beams. We are interested in the transport of such packets from one side of the well to the other, and potential escape from the trap. We theoretically investigate how the time-dependent escape rate of atoms from the trap is influenced by the chaotic dynamics of the potential and by the inherent nonlinearity induced by atom-atom interactions.

Saturday, June 9, 2007 8:00AM - 10:12AM –
Session W5 Quantum Measurement and Quantum Information TELUS Convention Centre Macleod A3-A4

8:00AM W5.00001 Measuring an unknown phase with quantum-limited precision using nonlinear beam splitters, YUPING HUANG, Ohio University, MICHAEL MOORE, Michigan State University — High precision phase measurement is currently a central goal of quantum interferometry. In general, the precision is described by the phase estimation uncertainty $\Delta \theta$, which is characterized by two scaling behaviors, shot-noise limited with $\Delta \theta \sim 1/\sqrt{N}$ and Heisenberg limited with $\Delta \theta \sim 1/N$ (N the total particle number). According to Bayesian analysis, Heisenberg limited precision for $\theta = 0$ can be achieved in a Mach-Zehnder interferometer with $(N-1, N+1) + (N+1, N-1))/\sqrt{2}$ as input state based and a single measurement or $|N,N\rangle$ input based on multiple measurements. As $\theta$ deviates from zero, both schemes degrade rapidly to worse than shot-noise-limited precision. In contrast, a Quantum Fourier Transform (QFT) based interferometer can measure an arbitrary $\theta$ at Heisenberg limited precision, but requires a quantum computer. To extend the range of precisely measurable $\theta$ without a quantum computer, we propose using nonlinear beam splitters. We find that this can achieve nearly Heisenberg-limited precision over a wide range of $\theta$. This scheme can be implemented in a bimodal Bose-Einstein condensate (BEC) system with tunable scattering length. Numerical calculations show: i) at $\theta = 0$, $\Delta \theta \sim 1/N$; and ii) as $\theta$ moves towards $\pm \pi/2$, the precision crosses over smoothly to $\Delta \theta \sim 1/\sqrt{N}$, providing a wide range over which the precision is nearly Heisenberg limited.
8:12AM W5.00002 Interaction- and measurement-free quantum information processing with single-atom and/or single-photon qubits, MICHAEL MOORE, Michigan State University, YUPING HUANG, Ohio University — Interaction-free measurement (IFM) uses quantum interference to allow a single photon to detect a perfectly absorbing object without the photon interacting with the object directly. In high-efficiency IFM, the Quantum Zeno Effect is employed to increase the success probability from the original 50% to (N−1)/N, where N is the number of cycles the photon makes through the device and a 1. In principle IFM protocols allow the hyperfine state of a single atom to become entangled with the polarization of a single photon. To date, attempts to employ this entanglement to create universal atom-atom quantum logic gates, such as CNOT gates, have not succeeded in achieving (N−1)/N efficiency. In addition, they also require the detection of ancillary photons. At present, single-photon detection cannot be implemented experimentally with high efficiency. By making several key modifications, we have developed a pair of complimentary Interaction-Free quantum gates that can be used to design high-efficiency atom-atom, atom-photon, and photon-photon CNOT and state-transfer protocols, which do not require the use of photodetectors or measurements of any kind. In addition, we have analyzed the effects of imperfect atomic selection rules due to tight-focussing of the photons and tight trapping of the atoms, and identified the scattering parameter on which the efficiency depends sensitively.

8:24AM W5.00003 Adaptive Quantum State Detection through Repetitive Mapping, DAVID HUME, NIST/ University of Colorado, TILL ROSENBAND, DAVID WINELAND, JIM BERGQUIST, NIST — State detection plays an important role in quantum information processing and quantum limited metrology. In some quantum systems direct detection is impossible or inefficient. This can be overcome by coupling the primary quantum system to an ancillary system used for measurement [1]. The measurement process consists of mapping the primary state to the ancilla followed by ancilla detection. If the measurement does not affect the projected populations of the primary system, it may be repeated yielding higher fidelity. Using two trapped ion species (27Al+ and 9Be+) as the primary and ancillary systems, we demonstrate high-fidelity measurement despite imperfect information transfer and ancilla detection. An adaptive measurement strategy allows for multiple qubit state discrimination with one ancilla. This opens the way for several applications in quantum information processing and advances our optical clock effort. [1] P.O. Schmidt, et. al. Science 309 749 (2005)

8:36AM W5.00004 Atom interferometry, microscopy, complementarity, and the perfect lens, BARRY SANDERS, KARL-PETER MARZLIN, University of Calgary, PETER KNIGHT, Imperial College London — Development of the ‘perfect lens’ poses an interesting challenge to standard concepts of complementarity manifested in interferometric which-way vs fringe visibility experiments. We show that a ‘microscope’ with a ‘perfect lens’ provides the extremal point of maximum which-way information in atom interferometry, and our theory rigorously connects complementarity in interferometry with the standard position-momentum Heisenberg uncertainty relation.

8:48AM W5.00005 Distinguishability of a Tripartite Unextendible Product Basis using Local Operations and Classical Communication, MICHAEL DUROCHER, BARRY C. SANDERS, University of Calgary, JONATHAN WALGATE, Perimeter Institute for Theoretical Physics — Quantum states must be distinguished every time we need to obtain information from a system. Here, we quantify multi-partite state distinguishability with different measurement settings; this leads to important results in the case of an important tripartite system. Specifically, we analyze the smallest tripartite Unextendible Product Basis (UPB). This UPB has interesting symmetries and is not entangled, hence interesting here. Our work is an important step towards full quantitative analysis of local information available in locally indistinguishable sets of states. We consider the case in which the parties are restricted to Local Operations and Classical Communication (LOCC), which makes perfect distinguishability impossible in this situation. We also discuss our discovery of optimal (maximum extraction of information as given by the Shannon entropy decrease) protocols for distinguishing our UPB.

9:00AM W5.00006 ABSTRACT HAS BEEN MOVED TO J5.00012 —

9:12AM W5.00007 Three Undistinguished Quantum Radiators in Quantified Cavity Field, NICOLAE ENAKI, TUDOR ROSCA, Institute of Applied Physics of Academy of Sciences, Chisinau MD2028, R. Moldova — In many problems of quantum information it is used the distinguished ensembles of qubits in the realization of quantum states of registers. On the other hand, the Bose-Einstein condensations of atomic ensembles give us the possibility to regard two-level atoms like an undistinguished ensemble. In this representation N two-level atoms have a more reduced number of collective states. In general case, N two-level atoms with the number of states 2^N+1 can be reduced to N−1 states in processes of coherent excitation in according with the undistinguished principle between the radiators. In this paper the behavior of ensemble consisted from three undistinguished atoms in interaction with one mode of microcavity is discussed. This problem is reduced to N+1 equations. We reduced the number of 2^3 states for three two-level radiators to four levels and solved exactly the system of linear equations. The application of cooperative effect of absorption and emission in micromasers is discussed. The condition for lasing and trapping effects is found. The quantum proprieties of cooperative generated field in the cavity are studied.

9:24AM W5.00008 Fundamental physics issues of multilevel logic in developing a parallel processor, ANIRBAN BANDYOPADHYAY, ICYS, KAZUSHI MIKI, NIMS, ICYS AND NANOARCHITECTURE GROUP COLLABORATION — In the last century, On and Off physical switches, were equated with two decisions 0 and 1 to express every information in terms of binary digits and physically realize it in terms of switches connected in a circuit. Apart from memory-density increase significantly, more possible choices in particular space enables pattern-logic a reality, and manipulation of pattern would allow controlling logic, generating a new kind of processor. Neumann’s computer is based on sequential logic, processing bits one by one. But as pattern-logic is generated on a surface, viewing whole pattern at a time is a truly parallel processing. Following Neumann’s and Shannons fundamental thermodynamical approaches we have built compatible model based on series of single molecule based multibit logic systems of 4-12 bits in an UHV-STM. On their monolayer multilevel communication and pattern formation is experimentally verified. Furthermore, the developed intelligent monolayer is trained by Artificial Neural Network. Therefore fundamental weak interactions for the building of truly parallel processor are explored here physically and theoretically.
for generalized Spin(n+1)/Spin(n) are n-dimensional spheres \( S^n \). Berry and Wilczek-Zee non-Abelian phases. It is well known that construction of the Bloch Sphere is based on the SU(2)=Spin(3) Lie group isomorphism. Since bundles, embedded in the SU(4) manifold and to identify relevant holonomies. Geometrically these fiber bundles are even simpler than fiber bundles supporting Berry and Wilczek-Zee non-Abelian phases. We exploit this property to construct a new set of \([\text{Spin}(n+1)/\text{Spin}(n)]\times S^n\) fiber bundles, embedded in the SU(4) manifold and to identify relevant holonomies. Geometrically these fiber bundles are even simpler than fiber bundles supporting Berry and Wilczek-Zee non-Abelian phases. As an example we derive a set of linear dynamic equation for generalized Bloch sphere, describing an evolution of a 4-level quantum system.

9:36AM W5.00009 Spherical Geometry of Two Qubit Unitary Operators. DMITRY USKOV, Tulane University, RAVI RAU, Louisiana State University — Geometric and algebraic properties of the SU(4) group of two-qubit transformations are much richer than corresponding properties of an arbitrary SU(N) group because there exists an accidental isomorphism between the SU(4) Lie group and the Spin(6) Lie group (a spinor form of orthogonal rotations in Euclidean 6-dimensional space). We exploit this property to construct a new set of [Spin(n+1)/Spin(n)]×Spin(n) fiber bundles, embedded in the SU(4) manifold and to identify relevant holonomies. Geometrically these fiber bundles are even simpler than fiber bundles supporting Berry and Wilczek-Zee non-Abelian phases. It is well known that construction of the Bloch Sphere is based on the SU(2)=Spin(3) Lie group isomorphism. Since quotients spaces Spin(n+1)/Spin(n) are n-dimensional spheres \( S^n \), the chain of embedded subgroups Spin(3), Spin(4), Spin(5) allows to complete the Bloch Sphere construction for the SU(4) case by a combination of spheres of higher dimensions \( S^1, S^4, S^5 \). As an example we derive a set of linear dynamic equation for generalized Bloch sphere, describing an evolution of a 4-level quantum system.

9:48AM W5.00010 The Spekkens Toy Model Revisited1. MICHAEL SKOTNIOTIS, AIDAN ROY, BARRY C. SANDERS, University of Calgary — We review the toy model introduced by R.W. Spekkens, and show that the operations on a single toy bit belong to the group \( S_2 \) semi direct \( Z_2 \). The original group \( S_2 \) is shown to be a subgroup of this. We show that this group does not violate the basic principle of the toy model nor any quantum mechanics and we show its natural extension to the two toy bit case.

1Research supported by NSERC.

10:00AM W5.00011 De Broglie waves as a manifestation of clock desynchronization1. WILLIAM BAYLIS, Physics Dept., Univ. of Windsor — De Broglie matter waves, such as used in atom optics or for interference in a BE condensate, can be viewed as the relativistic effect that spatially separated clocks that are synchronized in the rest frame become desynchronized when set in motion. The “clocks” here are the quantum oscillation of a stationary state. The usual de Broglie wavelength and superluminal wave velocity are easily derived. As simple and obvious as this picture is, I have not seen it described before. It is not only a nice example of clock desynchronization, it also has an interesting consequence: the oscillation of the stationary state must be at the Zitterbewegung frequency, that is, the corresponding energy must include the rest-mass energy. Of course most experiments are only sensitive to frequency differences.

Saturday, June 9, 2007 8:00AM - 9:24AM — Session W6 Optical Diagnostics and Characterization TELUS Convention Centre Macleod BC

8:00AM W6.00001 Optical Absorption in Artificial Atoms. YIMING MI, School of Materials Engineering, Shanghai University of Engineering Science, SUICHI IWATA, RACE, The University of Tokyo, RACIE, THE UNIVERSITY OF TOKYO COLLABORATION — Optical transitions in an artificial atom (AA) interacting with longitudinal optical phonons are studied theoretically, which can be solved exactly under the condition of finite number of carrier levels in the system. The linear optical properties are calculated, and the obtained results are compared with the ones of other theoretical model. Perhaps, the acquired theoretical results are of great interest and would get precise validations experimentally in near future.

8:12AM W6.00002 Energy relaxation and dephasing in CARS. SVETLANA MALINOVSKAYA, Department of Physics and Engineering Physics, Stevens Institute of Technology, Hoboken, NJ 07030 — We use the adiabatic passage control scheme developed for the CARS spectroscopy to investigate the energy relaxation and phase relaxation as factors of the optical polarization decay. We show that in strong fields the dynamics of induced polarization via adiabatic passage is dependent on phase relaxation, and to less extent on energy relaxation for characteristic times close to pulse duration. We justify our conclusions with the dressed state dynamics analysis.

8:24AM W6.00003 Continuous Bremsstrahlung in Trojan atoms and molecules. MATT KALINSKI, Utah State University — We present a fully relativistic approach to the electron radiation in Trojan atoms, atoms of hydrogen in circularly polarized electromagnetic field. Unlike for the normal scattering event the Bremsstrahlung is the continuous process and the cyclotron radiation due to circular pseudo-scattering, when the electron is internally excited. Depending on the electromagnetic coupling order and the relativistic \( v/c \) order the corrections can be interpreted as the native spontaneous emission and the Unruh-Davies effect. All contributions have their classical correspondence in equivalent parts of Lienard-Wiechert potentials.

8:36AM W6.00004 Escherichia coli identification and strain discrimination using nanosecond laser-induced breakdown spectroscopy. STEVEN REHSE, JONATHAN DIEDRICH, Wayne State University, Department of Physics and Astronomy, SUNIL PALCHAUDHURI, Wayne State University, Department of Immunology and Microbiology — Three strains of Escherichia coli, one strain of black mold and one strain of Candida albicans yeast have been analyzed by laser-induced breakdown spectroscopy (LIBS) using nanosecond laser pulses. All microorganisms were analyzed while still alive and with no sample preparation. Nineteen atomic and ionic emission lines have been identified in the spectrum, which is dominated by calcium, magnesium and sodium. A discriminant function analysis (DFA) has been used to discriminate between the bio-types and E. coli strains. This is the first demonstration of the ability of the LIBS technique to differentiate between different strains of a single species.

8:48AM W6.00005 Recombination fluorescence in ultracold plasmas. SCOTT BERGESON, Brigham Young University, FRANCIS ROBICHEAUX, Auburn University — The expansion dynamics of ultracold neutral plasmas are determined by electron physics. Three-body recombination and electron-Rydberg scattering heat the plasma electrons at early times and drive the expansion. The details of these processes are well understood in weakly-coupled plasmas. However, these processes may proceed differently in strongly-coupled neutral systems. We present a study of recombination fluorescence in ultracold plasmas. At low densities, we find good agreement between theory and experiment. At higher densities, theory and experiment diverge.

9:00AM W6.00006 Ion Temperature and Expansion Velocity Measurements Through Fluorescence Imaging in Ultracold Neutral Plasmas. JOSE CASTRO, HONG GAO, PRIYA GUPTA, SAMPAD LAHA, CLAYTON SIMIEN, THOMAS KILLIAN, Department of Physics and Astronomy and Rice Quantum Institute, Rice University, Houston, TX 77005 — Imaging probes in Ultracold Neutral plasmas are used for studying strongly coupled systems. Doppler broadening of the light-scattering spectrum provides information on ion temperature and velocity. Absorption imaging shows Doppler broadening due to the combined effects of the radially directed expansion velocity and the random thermal motion of the ions. To distinguish these two quantities, fluorescence imaging of Ultracold Neutral Plasmas is used to produce a spatially-resolved spectrum that is Doppler-broadened due to thermal ion velocity and shifted due to ion expansion velocity.
well isolated from the electron spin, even during optical polarization and measurement of the electronic state. Finally, we observe coherent interactions between optical excitation, we demonstrate robust, room-temperature initialization of the two-qubit register formed by the electronic spin and the nearest-neighbor which modifies its energy levels and magnetic moment, effectively distinguishing it from the rest of the spin bath. By manipulating the NV center via microwave nuclear spins, which cause the loss of coherence. A proximal nuclear spin can be addressed individually because of quantum back-action from the electron, energy use of this device. In the second experiment a femtosecond laser pump-probe experiment on a field emission tip was performed. Control of the electron beam passes through three gold coated nano-fabricated gratings and reveals interference fringes. Measured dephasing processes poses limitations on the low spectroscopy. In addition, a 0.1 K Penning trap that is also a cylindrical microwave cavity is used to control the radiation field, to suppress spontaneous emission by more than a factor of 100, to control cavity shifts, and to eliminate the blackbody photons that otherwise stimulate excitations from the cyclotron ground state. Finally, great signal-to-noise for one-quantum transitions is obtained using electronic feedback to realize the first one-particle self-excited oscillator. The new methods may also allow a million times improved measurement of the 500 times smaller antiproton magnetic moment. New Measurement of the Electron Magnetic Moment B. Odom, D. Hanneke, B. D’Urson and G. Gabrielse, Phys. Rev. Lett. 97, 030801 (2006). New Determination of the Fine Structure Constant G. Gabrielse, D. Hanneke, T. Kinoshita, M. Nio, B. Odom, Phys. Rev. Lett. 97, 030802 (2006). AIP Physics Story of the Year (Phys. News Update, 5 Dec. 2006)

- Science 313, 448-449 (2006)
- Physics Today, 15-17 (August, 2006)
- Cern Courier (October 2006)
- Physics World (March 2007)

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Saturday, June 9, 2007 10:30AM - 1:30PM –
Session X1 Hot Topics Session  TELUS Convention Centre Macleod BC

10:30AM X1.00001 New Measurement of the Electron Magnetic Moment and the Fine Structure Constant 1, GERALD GABRIELSE, Harvard University — Remarkably, the famous UW measurement of the electron magnetic moment has stood since 1987. With QED theory, this measurement has determined the accepted value of the fine structure constant. This colloquium is about a new Harvard measurement of these fundamental constants. The new measurement has an uncertainty that is about six times smaller, and it shifts the values by 1.7 standard deviations. One electron suspended in a Penning trap is used for the new measurement, like in the old measurement. What is different is that the lowest quantum levels of the spin and cyclotron motion are resolved, and the cyclotron as well as spin frequencies are determined using quantum jump spectroscopy. In addition, a 0.1 K Penning trap that is also a cylindrical microwave cavity is used to control the radiation field, to suppress spontaneous emission by more than a factor of 100, to control cavity shifts, and to eliminate the blackbody photons that otherwise stimulate excitations from the cyclotron ground state. Finally, great signal-to-noise for one-quantum transitions is obtained using electronic feedback to realize the first one-particle self-excited oscillator. The new methods may also allow a million times improved measurement of the 500 times smaller antiproton magnetic moment. New Measurement of the Electron Magnetic Moment B. Odom, D. Hanneke, B. D’Urson and G. Gabrielse, Phys. Rev. Lett. 97, 030801 (2006). New Determination of the Fine Structure Constant G. Gabrielse, D. Hanneke, T. Kinoshita, M. Nio, B. Odom, Phys. Rev. Lett. 97, 030802 (2006). AIP Physics Story of the Year (Phys. News Update, 5 Dec. 2006)

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1Experiments at Harvard were supported by the NSF AMO and theory programs.

11:06AM X1.00002 Electron Matter Optics1, HERMAN BATELAAN, University of Nebraska-Lincoln — Our group has realized a Mach-Zehnder interferometer for electron matter waves and a source of femtosecond electron pulses. In the first experiment a highly collimated electron beam passes through three gold coated nano-fabricated gratings and reveals interference fringes. Measured dephasing processes poses limitations on the low energy use of this device. In the second experiment a femtosecond laser pump-probe experiment on a field emission tip was performed. Control of the electron emission mechanisms, which are multi-photon absorption and optical field tunneling, may be useful for the production of attosecond electron pulses. We will discuss the use of the first device to test the dispersionless nature of the Aharonov-Bohm effect and the use of the second device to test the macroscopic limit of the Aharonov-Bohm effect.

1Supported by NSF.

11:42AM X1.00003 Coherent manipulation of individual electronic and nuclear spin qubits in diamond1, LILIAN CHILDRESS, Harvard University — The complex environment of solid-state quantum bits is generally believed to form a central challenge for solid state realizations of quantum information science. We here demonstrate how the environment of a single electronic spin can be understood, controlled, and utilized as a resource. Specifically, coherent manipulation of a single electronic spin associated with a nitrogen-vacancy (NV) center in diamond was used to probe its interactions with the 13C nuclear spin bath formed by isotopic impurities in the surrounding diamond lattice. We show that this environment is effectively separated into a set of individual, proximal 13C nuclear spins which are coupled coherently to the electron spin, and the remainder of the 13C nuclear spins, which cause the loss of coherence. A proximal nuclear spin can be addressed individually because of quantum back-action from the electron, which modifies its energy levels and magnetic moment, effectively distinguishing it from the rest of the spin bath. By manipulating the NV center via microwave and optical excitation, we demonstrate robust, room-temperature initialization of the two-qubit register formed by the electronic spin and the nearest-neighbor 13C nuclear spin. Within this register, arbitrary quantum states can be transferred between the electronic and nuclear spin, while the nuclear spin qubit can be well isolated from the electron spin, even during optical polarization and measurement of the electronic state. Finally, we observe coherent interactions between individual nuclear spins, and demonstrate that they have excellent coherence properties, approaching those of isolated atoms and ions. Such registers may be used as a basis for scalable, optically coupled quantum information systems.

1This work was supported in part by the NSF Career Award, ARO MURI, and the Packard, Sloan, and Hertz Foundations.
12:18PM X1.00004 Producing and detecting correlated atoms in degenerate gases, CHRIS WEST-BROOK, Laboratoire Charles Fabry de l’Institut d’Optique — This talk will cover two conceptually simple experiments in which atom correlations have been demonstrated in our laboratory. In the first experiment we reproduced the atomic analog of the celebrated Hanbury Brown and Twiss experiment for photons. Correlations between atoms appear because of a constructive interference between two alternate possibilities for detecting two atoms in two detectors. We are able to reconstruct the two particle correlation function in three dimensions. This interference effect results in an enhanced probability to detect two bosons close together, provide the Bose gas is not degenerate, and a decreased probability to detect two fermions close together. The interference absent for atoms in a Bose-Einstein condensate. We have demonstrated a second type of correlation resulting from the atomic analog of four wave mixing. Two condensates are produced with a well defined relative velocity. Binary collisions (or spontaneous four wave mixing) results in atom pairs with equal and opposite momenta. Interestingly a colinear Hanbury Brown Twiss correlation is also present. We will discuss the data and our progress in their quantitative understanding. The possibility of observing a sub-Poissonian dispersion in the relative number of atoms in opposite directions will be discussed.

12:54PM X1.00005 Recording the Birth and Death of a Photon in a Cavity, MICHEL BRUNE, Ecole Normale Superieure —