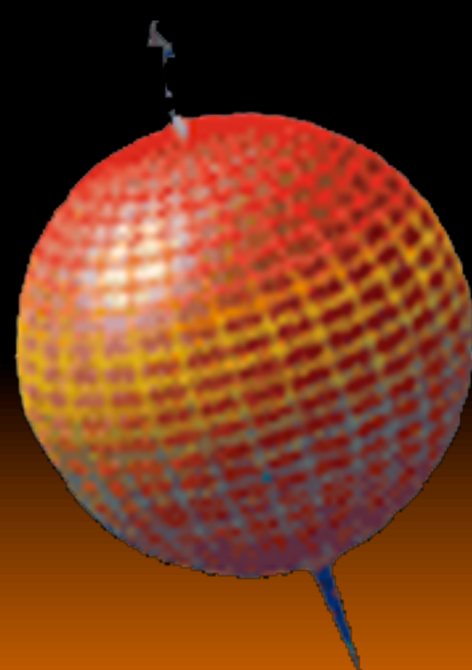
LANL Quantum Workshop

Los Alamos Research Park Building
Room 203

April 28, 2010



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The LANL Quantum Initiative, the Institutes Office, and CNLS are sponsoring this Laboratory-wide workshop on Quantum Science and Technology. The purpose of the workshop is to update all those interested in quantum research at the Laboratory on recent accomplishments, to discuss future directions, and to initiate new collaborations. We hope that all research relevant to quantum entanglement and quantum coherence conducted in and around the Laboratory will be represented.

The daylong program will consist of nine talks, along with a poster session that will run over an extended lunch break to provide ample time for discussion. Poster presenters will be able to present a two-minute "advertisement" for their poster in an oral session immediately before the posters.

For more information go to the following web site: http://quantum.lanl.gov or contact Malcolm Boshier, 505-665-8892, boshier@lanl.gov.

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Agenda

UNCLASSIFIED

LANL Quantum Workshop

Los Alamos Research Park, Room 203

April 28, 2010

Wednesday, April 28, 2010

9:00 Welcome .... Malcolm Boshier
Quantum Initiative/P-21

9:10 *Quantum Noise in Slow and Fast Light* .... Peter Milonni
Physics of Condensed Matter & Complex Systems/T-4

9:45 *New Directions in Quantum Communications* .... Richard Hughes
Applied Modern Physics/P-21

10:20 *Quantum Channel Capacities* .... Jon Yard
Information Sciences/CCS-3

10:55 Break

11:15 "Two-Minute" Poster Summary Presentations

12:00 Poster Session and Lunch

1:30 *Quantized Circulation in a Base Einstein Condensate* .... Malcolm Boshier

2:05 *Coherent Quantum Noise-Cancellation for Opto-Mechanical Sensors* .... Mankei Tsang
University of New Mexico/UNM

2:40 *Micro-device Technologies for Atomic Physics Based Quantum Information Experiments* ... Matthew Blain
Sandia National Laboratories/SNL

3:15 Break

3:30 *Macroscopic Quantum Superposition and Tunneling in Cold Atom Systems* .... Dima Mozyrsky
Physics of Condensed Matter & Complex Systems/T-4

4:05 *Observation of the Surface State and Fractional Landau Quantization in a Topological Insulator* .... Ross McDonald
Condensed Matter & Magnet Science/MPA-CMMS

4:40 *Critical Dynamics of Decoherence* .... Bogdan Damski
Physics of Condensed Matter & Complex Systems/T-4

5:15 Conclusion

1. Quantum noise in slow and fast Light

Peter Milonni (T-4)

Following a brief review of slow and fast light, the fundamental noise properties of propagation through optical media with gain or loss will be considered. For purely quantum mechanical reasons, any gain or loss process will add noise to a transmitted light field. A relation is derived between the noise figure describing the decreased signal-to-noise ratio of the transmitted laser pulse and the fractional delay or advancement of the pulse. For an ideal gain medium the noise figure never exceeds a factor of two. For a loss medium, there is no limit to how large the noise figure can become. The increased noise in this case is the result of the random loss of photons from the optical field.

2. New directions in quantum communications

Richard Hughes (P-21)

In my talk I will describe some recent results from our team in which quantum and optical communications have been combined in a single experiment, as well as prospects for going beyond the laboratory environment. I will also describe an information science research path for new protocols that will allow quantum communications to provide scalable, future proof secure networking.

3. Quantum channel capacities

Jon Yard (CCS-3)

The capacity of a communication channel is the highest rate at which it can reliably transmit information. The classical theory of capacity was introduced by Shannon over 60 years ago, during which time it was extended to networks, the study of information-theoretic security, and more recently to channels that are quantum mechanical. The quantum theory allows the analysis of practical channels such as free-space and optical fiber channels, while also providing a paradigm for studying the kind of noise that would corrupt future technologies like quantum computers. In this talk, I will give an overview of capacity theory for quantum channels, showing that while it shares certain central features with the classical theory, it also departs from that theory in fundamental and interesting ways. This gives a richer theory in which several fundamental challenges still remain to be solved even in the case of point-to-point communication.

4. Quantized circulation in a Bose-Einstein condensate

Malcolm Boshier (P-21)

We recently developed a technique for creating and manipulating Bose-Einstein condensates in arbitrary optical dipole potentials "painted" with a rapidly-moving focused laser beam. We have now used this system to study the response of a toroidal condensate to rotation, leading to the first demonstration of quantized circulation in a gaseous BEC. In the experiment a small potential barrier within a toroidal trap rotates as the condensate is formed. The barrier is then lowered adiabatically and the resulting momentum distribution studied by absorption imaging after ballistic expansion. The quantized response to rotation is clear even in the raw absorption images, where the diameter of the central hole seen in the time of flight images changes in steps corresponding to different integer winding number (the number of 2π phase steps around the toroid) of the superfluid flow. The observed winding numbers increase with the initial stirring frequency, and we have so far been able to create flows with winding number up to five. The system should enable clean studies of fundamental superfluid phenomena such as critical velocity and the metastability of superfluid flow.

5. Coherent quantum noise cancellation for opto-mechanical sensors

Mankei Tsang (UNM)

In quantum sensing applications, such as opto-mechanical force sensing and atomic magnetometry, a well known method of quantum noise suppression is quantum estimation, which processes the measurement record and estimates the signal corrupted by quantum noise using one's a priori knowledge of the experiment. While the optimal estimation strategy can be designed using a Bayesian approach for a given experiment [see, for example, M. Tsang, Phys. Rev. Lett. **102**, 250403 (2009)], quantum estimation theory does not specify how one should design or improve the experiment for optimal sensing performance. Here we propose the concept of quantum noise cancellation (QNC), which may be regarded as a quantum version of the noise cancellation technique that has been widely employed in commercial products, such as noise-cancellation headphones. Using an opto-mechanical sensor as an example, we show how QNC is able to remove the measurement back-action noise and allows one to overcome the standard quantum limit of force sensing. In the context of quantum control theory, QNC can be regarded as a novel example of coherent feedforward quantum control that can out-perform existing measurement-based estimation and control techniques.

6. Micro-device technologies for atomic physics based quantum information experiments

Matthew Blain (SNL)

Micro-fabricated devices are taking on an increasingly important role in quantum information experiments that utilize atoms and photons and are expected to be an enabling technology for scaling the number of quantum interactions to achieve a useful quantum processor or network. The key attribute of such devices is physical features defined by photolithographic patterning. We report on our efforts in designing, fabricating, and characterizing surface ion traps, optical micro-cavities, and multi-level conductor atom chip devices for atomic physics research.

7. Macroscopic quantum superposition and tunneling in cold atom systems

Dima Mozyrsky (T-4)

We will discuss possible realizations of the “Schrodinger cat” states in cold atom systems. We argue that the recently developed (at LANL) “painted potential” technique allows one to realize and measure such states. In particular we will consider macroscopic properties of a Bose Einstein condensate (BEC) confined in a ring-shaped potential with a Josephson junction. We find that in many aspects this system is similar to a superconducting flux-qubit device: For example, it possesses a set of metastable states corresponding to macroscopically different BEC states carrying non-zero supercurrent. We will discuss possibilities to control and to detect these states within currently available experimental technique.

8. Observation of the surface state and fractional Landau quantization in a topological insulator

Ross McDonald (MPA-CMMS)

The resurgence of interest in Bi_2Se_3, and related compounds, has been driven by the prediction that these materials can fulfill the requirements for the observation of a topological insulating state, i.e. the electronic spectrum being fully gapped in the bulk with a gapless, dissipationless surface state. The key to interpreting transport data from these materials is resolving the relative contributions of surface and bulk conductivity. To this end, we use high magnetic fields –beyond the quantum limit of the bulk– and a combination of ac-transport, rf- and microwave-spectroscopy to selectively couple to the surface conductivity. For bulk carrier concentrations ~10^{17} cm^{-3} we observe a crossover from quantum oscillations indicative of a small 3D Fermi surface, to cyclotron resonance indicative of a 2D surface state, in the frequency range of a few GHz. For bulk carrier concentrations ~10^{16} cm^{-3} we observe integer and fractional Landau quantization in R_{xx} and R_{xy} corresponding to the 2D state. The implications of these observations with respect to the existence of a topologically protected Dirac-cone and quasi-particle interactions among the Dirac fermions will be discussed.

9. Critical dynamics of decoherence

Bogdan Damski (T-4)

The quantum-classical border Niels Bohr postulated to account for the definiteness of measurement outcomes is explained by decoherence. Decoherence, as a destroyer of quantum coherence and entanglement, is also a respected foe in novel applications of quantum physics (such as quantum computing or quantum metrology). So far, studies of decoherence focused on systems prepared typically in a Schrödinger cat-like superposition, and then instantaneously coupled to an otherwise static environment. We study decoherence induced by many-body dynamic environment undergoing a non-equilibrium (quantum) phase transition. As environment "monitors" the quantum system, its sensitivity -- and, consequently, efficiency of decoherence -- is amplified by a phase transition, as is often the case in the real world detectors (bubble chambers, photographic emulsions, or rhodopsin in our eyes). We show that decoherence happens almost exclusively as the critical point of the environment is traversed, and is significantly enhanced by its non-equilibrium phase transition dynamics. Our calculation yields a simple expression that relates decoherence to the universal critical exponents in a way that parallels theory of topological defect creation in non-equilibrium phase transitions.

1. Quantum Eraser and Phase-Matching for Exponential Spin-Squeezing via Coherent Optical Feedback

Collin Trail (UNM)

A scheme for squeezing collective atomic spin states via coherent optical feedback was proposed by M. Takeuchi et. al., Phys. Rev. Lett. **94**, 023003, 2005. In the first pass, the Faraday effect acts to entangle the light with the atoms. In a coherent second pass, this information is imprinted back onto the atoms, creating an effective nonlinear interaction and entanglement between atoms. However, the light is still entangled to the atoms when it escapes, leading to substantial decoherence, and moreover, the interaction slowly rotates the system out of sync with the squeezing axis, both of which result in suboptimal squeezing. We show how the addition of a quantum eraser and phase matching can lead to radically improved exponential scaling. We analyze this system in the presence of realistic imperfections such as photon scattering, optical pumping, losses in transmission and reflection, finite detector efficiency, and nonprojective measurements, and show that spin squeezing near 10 dB should be possible..

2. Spin Squeezing Beyond Spin-1/2

Leigh Norris, Collin Trail and Ivan Deutsch (University of New Mexico)

Spin squeezed states have generated great interest for their possible applications in metrology and quantum information processing. Substantial research has been directed both at producing spin squeezed states and understanding the properties of the states themselves. This has uncovered a complex relationship between collective spin squeezing and the entanglement between the individual spins. Whereas spin squeezing scales monotonically with the two-body concurrence in an ensemble of spin $j=1/2$ particles, an analogous relationship for $j>1/2$ less clear. We explore this problem for an ensemble of alkali atomic spins interacting with a single spatial mode of the electromagnetic field through the Faraday effect, a system that has previously been used for spin squeezing protocols. We investigate how the amplified projection noise of the large spin atoms leads to enhanced entangling interactions due to increased measurement backaction on the atoms and whether this entanglement can be converted into meaningful spin squeezing through local unitary control.

3. Quantum-enhanced measurement using trapped ions

Warren E. Lybarger, Jr (P-21), Rolando Somma (T-4), Diego Dalvit (T-4), John Chiaverini (MIT Lincoln Labs), and Malcolm Boshier (P-21)

The application of algorithms and techniques from the realm of quantum information processing to the problem of metrology can enable better precision than is possible with traditional measurement protocols using similar resources. We describe plans for two proof-of-principle experiments that utilize an existing trapped ion quantum information processing apparatus to surpass the shot-noise limit to measurement precision; both experiments will demonstrate Heisenberg limited precision measurement of some parameter of an external field applied to a single ion. First, superpositions of internal atomic states may be used to more quickly achieve a prescribed precision in the measurement of external fields through use of a bit-by-bit iterative phase estimation algorithm via conditional coherent operations applied to an individual ion; in essence, a one dimensional version of a quantum Fourier transform. Second, the motional states of ions trapped in a 3D harmonic well may be put into superposition states (Schrödinger-cat-type states) that are more sensitive to displacements and rotations in phase space than are classical-like coherent motional states. These states may be created and the measurements may be carried out using standard logic operations and techniques from trapped-ion quantum computing.

4. Ion trapping at Sandia: junction shuttling, cryogenic cooling, and laser development

Francisco Benito, Grant Biedermann, Matt Blain, Robert Cook, Kevin Fortier, Walter Gordy, Shanalyn Kemme, David Moehring, Dan Stick, Chris Tigges (Sandia National Laboratory)

We will present results of the design, operation, and performance of surface ion micro-traps fabricated at Sandia. Recent progress in the testing of the micro-traps will be highlighted, including successful motional control of ions in a junction region, continued progress on building a cryogenic vacuum chamber for trap testing, and a narrow linewidth laser for motional heating rate measurements. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

5. A Micro Ion Frequency Standard

P. D. D. Schwindt, R. Olsson, K. Wojciechowski, D. Serkland, T. Statom, H. Partner, G. Biedermann, L. Fang, A. Casias, R. Manginell, Y.Y. Jau (Sandia National Laboratory)

We are developing a highly miniaturized trapped ion clock to probe the 12.6 GHz hyperfine transition in the ^{171}Yb ion. Our goals are to develop a clock that is less than 5 cm^3 in size, consumes <50 mW of power, and has a long-term frequency stability of 10^{-14} at one month. Realizing a clock of this size requires advanced technologies to create a miniaturized vacuum package with an integral linear ion trap, Yb source, and pump. Integrated light sources for photoionization, state preparation and detection and a low-phase-noise microresonator for use as a local oscillator must also be developed. We report on our design for this frequency standard and our progress toward its realization.

6. Ultrafast laser quantum control for explosives detection and control of molecular dynamics

Shawn McGrane, Margo Greenfield, Jason Scharff, David Moore (Shock and Detonation Physics Group)

The coupling of controllable femtosecond laser fields with machine learning algorithms is being employed to 1) enhance spectroscopic explosive detection capabilities and 2) control molecular excited state dynamics and chemical reactivity. The experimental methods of controlling and optimizing femtosecond laser fields will be introduced, and the opportunities for enhancing explosive detection will be described. Recent results from the Los Alamos part of a joint Los Alamos/Princeton project on Optimal Dynamic Detection of Explosives (ODD-Ex) will be detailed. These results include selective excitation of vibrational spectroscopic features by pulse shaping- essentially, a mixture of chemicals is exposed to the laser, but only the desired chemical emits a signal. Results on controlling electronic excited state chemistry will also be briefly described. These results point the way toward several promising paths of opportunity in the field of applied quantum control.

7. The Casimir Effect and the Role of Dissipation

F.S.S. Rosa, D.A.R. Dalvit and P.W. Milonni (T-4)

The derivation of Casimir forces between dielectrics can be simplified by ignoring absorption, calculating energy changes due to displacements of the dielectrics, and only then admitting absorption by allowing permittivities to be complex. As a first step towards a better understanding of this situation we consider in this paper the model of a dielectric as a collection of oscillators, each of which is coupled to a reservoir giving rise to damping and Langevin forces on the oscillators and a noise polarization acting as a source of a fluctuating electromagnetic field in the dielectric. The model leads naturally to expressions for the quantized electric and magnetic fields that are consistent with those obtained in approaches that diagonalize the coupled system of oscillators for the dielectric medium, the reservoir, and the electromagnetic field. It also results in a fluctuation-dissipation relation between the noise polarization and the imaginary part of the permittivity. Our main result is the derivation of an expression for the QED energy density of a uniform dispersive, absorbing media in thermal equilibrium. The spectral density of the energy is found to have the same form with or without absorption. We also show how the fluctuation-dissipation theorem ensures a detailed balance of energy exchange between the (absorbing) medium, the reservoir and the EM field in thermal equilibrium.

8. Eddy currents and the Casimir Effect

Francesco Intravaia (T-4) and Carsten Henkel (Universität Potsdam)

In recent years the Casimir force has been the object of an exponentially growing attention both from theorists and experimentalists. A new generation of experiments paved the way for new challenges and spotted some shadows in the comparison to theory. Here we are going to focus on how dissipation in real materials affects the electromagnetic Casimir effect. This plays a central role in the ten-year long debate around the thermal correction to the Casimir Force. Our approach consists in isolating the contribution due to low-frequency modes that have no equivalent in the non-dissipative case. These modes will be identified as the quantum equivalent of eddy (or Foucault) currents, which are very well known for applications like induction ovens or magnetic braking. A detailed quantum-thermodynamical study of their contribution to the Casimir force permits us to isolate special features, to explain unusual behaviors and to shine new light on several aspects of the controversial thermal correction. This brings new physical understanding on the undergoing physical mechanisms and suggests new ways to engineer the Casimir effect.

9. Reentrant stability of BEC standing wave patterns

Ryan Kalas (T-4), Dmitry Solenov (T-4), and Eddy Timmermans (T-CNLS)

We describe standing wave patterns induced by an attractive finite-ranged external potential inside a large Bose-Einstein Condensate (BEC). As the potential depth increases, the time independent Gross-Pitaevskii equation develops pairs of solutions that have nodes in their wavefunction. We elucidate the nature of these states and study their dynamical stability. Although we study the problem in a two-dimensional BEC subject to a cylindrically symmetric square well potential of a radius that is comparable to the coherence length of the BEC, our analysis reveals general trends that are valid in two and three dimensions, independent of the symmetry of the localized potential well, and suggestive of the behavior in general short- and large-range potentials. One set of nodal BEC wavefunctions resembles the single particle n node bound state wavefunction of the potential well, the other wavefunctions resemble the n-1 node bound state wavefunction with a kink state pinned by the potential. The second state, though corresponding to the lower free energy value of the pair of n node BEC states, is always unstable, whereas the first can be dynamically stable in intervals of the potential well depth, implying that the standing wave BEC can evolve from being dynamically unstable to stable and back to unstable as the potential well is adiabatically deepened -- a phenomenon that we refer to as "reentrant dynamical stability".

10. Observation of Quantized Flow of a BEC in a Toroidal Trap

Changhyun Ryu, Kevin Henderson, and Malcolm Boshier (P-21)

Quantized circulation, one of the most important consequences of Bose-Einstein condensation, is fundamental to the understanding of superfluid phenomena. In a toroidal trap, Bose condensed atoms should flow with a well defined winding number, which makes it an ideal system to demonstrate the quantized nature of circulation. We used a scanning laser beam to create a toroidal trap. To rotate the atoms, a small potential barrier within the toroidal trap was rotated at a certain frequency and then the barrier was lowered to create a quantized flow state. The winding number of the flow was determined by the diameter of the central hole seen in a time of flight image of the condensate. The measurement showed diameters increasing stepwise with the stirring frequency. We observed flows with winding number up to 5. This is a clear demonstration of the quantization of the flow of atoms in a toroidal trap. Further study of critical velocity and metastability of flow of atoms will be very important in understanding the nature of superfluidity of atoms in a toroidal trap, especially in a 1D limit.

11. Metastable states and macroscopic quantum tunneling in a cold atom Josephson ring

Dmitry Solenov and Dima Mozyrsky (T-4)

We study macroscopic properties of a system of weakly interacting neutral bosons confined in a ring-shaped potential with a Josephson junction. We derive an effective low energy action for this system and evaluate its properties. In particular we find that the system possesses a set of metastable current-carrying states and evaluate the rates of transitions between these states due to macroscopic quantum tunneling and thermal activation mechanism. We discuss signatures of different metastable states in the time-of-flight images and argue that the effect is observable within currently available experimental technique. We also argue that BEC-Josephson ring systems can be a naturally accessible realization of a macroscopic two-state system in a cold atom framework.

12. Precision measurement of the nuclear spin polarization and its evolution in a far-off-resonance optical dipole trap

Fang Fang, Haiyan Wang, David Feldbaum, Andrew Hime, David Vieira and Xinxin Zhao (C-NR)

Laser cooled and trapped radioactive atoms provide an ideal sample for studying parity violation in beta decay. We have demonstrated the loading of ^{82}Rb atoms from a magneto-optical trap (MOT) to a far-off-resonance dipole trap formed by a YAG laser. A cold cloud of polarized atoms to 0.972(2) is prepared by optical pumping in the YAG dipole trap. The initial atomic distribution in the different Zeeman levels is measured using microwave transitions. The spin polarization is further purified to 0.987(1) in 10 seconds using resolved Zeeman spectroscopy techniques. After 10 seconds, the atomic polarization is maintained above 0.99 when the two-body collision loss rate between atoms in mixed spin states is greater than the one-body trap loss. Other factors affecting the nuclear spin are discussed also.

13. Quantum state reconstruction of the 16 dimensional hyperfine manifold in cesium via continuous measurement and control

Carlos Riofrio and Ivan Deutsch (UNM)

Quantum state reconstruction techniques based on weak continuous measurement have the advantage of being fast, accurate, and almost non-perturbative. Moreover, they have been successfully implemented in experiments on large spin systems (PRL **97**, 180403 (2006)). In this poster, an application of the reconstruction algorithm developed by Silberfarb et al. (PRL 95, 030402 (2005)) is presented for the reconstruction of quantum states stored in the 16 dimensional ground-electronic hyperfine manifolds (F=3, F=4) of an ensemble of 133Cs atoms controlled by microwaves and radio- frequency magnetic fields. Simulations showed that randomly generated control fields produce informationally complete measurement records and thus give high fidelity reconstructed states. Furthermore, exploration of appropriate operation regimes is shown for possible experimental implementation.

14. Building an Efficient and Selective Photon Detector using Amplification Without Inversion

Kevin Mertes and Michael Di Rosa (C-PCS)

We describe ongoing theoretical and experimental research at Los Alamos National Laboratory of a new technology for photon detection that exploits quantum processes to attain an unrivaled combination of high quantum efficiency and sharp spectral discrimination. The amplification without in-version (AWI) scheme we are exploring consists of a Λ system found in the excited states of ^{202}Hg. The construction of such a detector requires locking lasers to excited state transitions in ^{202}Hg. We demonstrate how to use saturated absorption spectroscopy and a simple-to-build discharge cell to achieve this. We also describe the theoretical and experimental results obtained to date using the detector. Funding is provided from the Laboratory Directed Research and Development program of the Los Alamos National Laboratory.

15. Quantum Sampling

Rolando Somma (T-4)

The goal of quantum sampling is to prepare a pure quantum state such that, after measurement, it is possible to sample from a specified probability distribution. We study quantum processes to sample from the Gibbs (thermal) distribution of particular classical models, and show that it is possible to speed-up classical Monte Carlo methods for the same purpose. The quantum processes are described in the adiabatic quantum model.

16. It's something about decoherence

Michael Zwolak, H. T.Quan, and W. H. Zurek (T-4)

Objectivity, a key property of the classical world, arises from the quantum substrate via the proliferation of redundant information into the environment where many observers can then intercept it and independently determine the state of the system. We demonstrate how non-ideal initial states of the environment (e.g., mixed states) affect its ability to act as a communication channel for information about the system. The environment's capacity for transmitting information is directly related to its ability to increase its entropy. Therefore, environments that remain nearly invariant under the Hamiltonian dynamics, such as very mixed states, have a diminished ability to transmit information. However, despite this, the environment almost always redundantly transmits information about the system.

17. Testing quantum adiabaticity with quench echo

H. T. Quan and W. H. Zurek (T-4)

Adiabaticity of quantum evolution is important in many settings. One example is the adiabatic quantum computation. Nevertheless, up to now, there is no effective method to evaluate the adiabaticity of the evolution when the eigenenergies of the driven Hamiltonian are not known. We propose a simple method to check adiabaticity of a quantum process for an arbitrary quantum system. We further propose a operational method for finding out the optimal quench scheme for the case when the initial and the final Hamiltonians are given. This method should help in implementing adiabatic quantum computation.

18. Magnetoencephalography with a fiber-coupled atomic magnetometer

Cort Johnson, Peter Schwindt, Michael Weisend (Sandia National Laboratory)

The detection of brain magnetic fields, or magnetoencephalography (MEG), has traditionally been performed with highly sensitive superconducting quantum interference devices (SQUIDs). Traditional SQUID systems require large capital expenditure and high maintenance costs because they must be maintained at liquid helium temperatures. Atomic magnetometers (AMs) are a potential noncryogenic alternative to SQUIDs and have recently demonstrated sub-femtotesla sensitivities [1]. In AMs, a vapor cell of alkali metal is heated to 200 ºC producing a high density atomic cloud. Circularly polarized laser light aligns the electron spins of the cloud to create a collective magnetic moment. The interaction of this moment with an external magnetic field changes the optical properties of the vapor, resulting in a measurable Faraday rotation of a probe laser. Although MEG with atomic magnetometers has been demonstrated [2], little effort has been spent to develop AMs that could be packaged in a whole head MEG system capable of source localization. With this goal in mind, we have designed a small-profile, fiber-coupled, rubidium-based AM. The design allows packing and placement of the AMs in a configuration similar to SQUID based MEG systems. Using a single sensor, we have successfully detected MEG signals from a human subject. The evoked responses from both median nerve stimulation and auditory stimulation were detected with our AM and a commercial SQUID-based system. The signals obtained from the atomic magnetometer and SQUID systems are comparable, opening up the possibility of developing a multi-sensor array for MEG source localization.

[1] I. K. Kominis, T. W. Kornack, J. C. Allred, and M. V. Romalis. Nature **422**, 596-599 (2003).
[2] H. Xia, A.B. Baranga, D. Hoffman, M.V. Romalis. Appl. Phys. Lett. **89** 211104/1-3 (2006).

19. The High Sensitivity and Resolution Ultracold Atom Magnetometer (UCAM)

Igor Savukov and Malcolm Boshier (P-21)

Atomic magnetometers (AMs), which are based on sensitive optical detection of the interaction of polarized atomic spins with magnetic field, are currently the most sensitive magnetometers. AMs are extremely important due to a large number of applications in geophysics, medicine, national security and many other fields. However, they have several performance limits due to the high temperature of operation of the atomic cells, stringent requirements on the magnetic field environment, and substantial distance from active atoms to the field source. To overcome these limitations, we propose to build a new type of AM, the ultra-cold atom magnetometer (UCAM) that will have much higher spatial resolution and higher sensitivity in a magnetically unshielded environment than the existing magnetometers.

20. Quantum Mechanical Origins of the Iczkowski-Margrave Model of Charge Equilibration

Steve Valone (Materials Science and Technology Division)

Most atomistic models of materials that attempt to account for charge equilibration do so through the Iczkowski-Margrave model [1]. This model describes the energy of an ion within a material as a function of its charge by a quadratic polynomial in charge. The linear coefficient has been interpreted as the Mulliken electronegativity and the quadratic coefficient as the band gap of the material. In spite of these pleasing interpretations, the origins of the polynomial are purely heuristic and not quantum mechanical. This model requires three charge states for each ion. Furthermore, as bonds are stretched, it has been shown that the quadratic dependence it fundamentally incorrect [2].

Here we investigate the question of charge dependence through a model hamiltonian. This model hamiltonian is developed from many-electron site hamiltonians that are open to exchange of electrons. The states of each site correspond to the allowed integer charge states and, by necessity, transitions between these states must be allowed. The charge dependence for a site energy is analyzed for both two [4] and three integer charge states [5]. Analysis shows that as bonds are stretched, the dominate contribution to the quadratic term is related to site hopping rather than the band gap. Cessation of hopping is what leads to the density-functional-theory result of Ref. 2. A general outcome of this model hamiltonian is a new, nonlinear model of chemical potential that has numerous ramifications for designing atomic potentials that can account for charge transfer.

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[2] J. P. Perdew, R. G. Parr, M. Levy, and J. L. Balduz, Jr., Phys. Rev. Lett. **49**, 1691 (1982).
[3] R. P. Feynman, Statistical Mechanics: A Set of Lectures, (Addison-Wesley, Reading MA, 1998), Ch. 2.
[4] S. M. Valone and S. R. Atlas, Phys. Rev. Lett. **97**, 256402 (2006).
[5] S. M. Valone, J. Li, and S. Jindal, IJQC **108**, 1452 (2008).

21. Finding centers of high-dimensional spheres using Schrödinger's equation

Aaron Denney (UNM)