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Monday, March 13, 2006 8:00AM - 11:00AM –
Session A40 TGQI DCMP: Quantum Entanglement Baltimore Convention Center 343

8:00AM A40.00001 A set of entanglement monotones for characterising experimental data
PETER LOVE, D-Wave Systems Inc, ALEC MAASSEN VAN DEN BRINK, D-Wave Systems Inc, MOHAMMED AMIN, D-Wave Systems Inc, ANATOLY SMIRNOV, D-Wave Systems Inc, MIROSLAV GRAJCAR, Institute for Physical High Technology, P.O. Box 100239, D-07702 Jena, Germany, EVGENI IL'ICHEV, Institute for Physical High Technology, P.O. Box 100239, D-07702 Jena, Germany, ANDREI IZMALKOV, Institute for Physical High Technology, P.O. Box 100239, D-07702 Jena, Germany, ALEX ZAGOSKIN, University of British Columbia — We define a set of elementary entanglement monotones and give a single measure of entanglement in terms of these monotones which is zero except on globally entangled states. We compute this measure for the ground state of a four qubit superconducting experimental system, and thus confirmed the presence of genuine four-qubit entanglement in the ground state.

8:12AM A40.00002 Dynamic learning of an experimental entanglement witness for an n-qubit system[1]
, KATHLEEN WALSH, ELIZABETH BEHRMAN, Department of Physics, Wichita State University, JAMES STECK, Department of Aerospace Engineering, Wichita State University, STEVEN SKINNER, Department of Electrical and Computer Engineering, Wichita State University — We extend our previous work on dynamic learning of an entanglement witness for a two-qubit system to n qubits, and show detailed comparisons for the two- and three-qubit systems to published entanglement measures. Our method can also be used for quNits, and can handle a small amount of noise and decoherence.

[1]Supported by NSF, ECS 0201995

8:24AM A40.00003 Dynamics and scaling of multi-partite entanglement
, FLORIAN MINTERT, Harvard University — We derive reliable estimates which allow for an efficient evaluation of a specific entanglement measure, concurrence, for further implementation in the monitoring of the time evolution of multipartite entanglement under incoherent environment coupling. This allows us to define a life time of entanglement for different realistic experimental scenarios, and investigate its scaling behaviour with increasing system size.

8:36AM A40.00004 The entanglement entropy and the Berry phase in solid states[1]
, SHINSEI RYU, KITP, UCSB, YASUHIRO HATSUGAI, Dept. of Appl. Phys., Univ. of Tokyo — The entanglement entropy (von-Neumann entropy) has been used to characterize the quantum entanglement of many-body ground states in strongly correlated systems. In this talk, we try to establish a connection between the lower bound of the von-Neumann entropy and the Berry phase defined for quantum ground states. As an example, a family of 1D Hamiltonians with two bands separated by a finite gap is investigated. We argue that when the Berry phase (Zak's phase) of the occupied band is equal to $\pm\pi\times$ (odd integer) and when the ground state respects a discrete unitary particle-hole symmetry (chiral symmetry), the entanglement entropy in the thermodynamic limit is at least larger than $\ln 2$ (per boundary), i.e., the entanglement entropy that corresponds to a maximally entangled pair of two spins. We also discuss it is related to vanishing of the expectation value of a certain non-local operator which creates a kink in 1D systems.

[1]Supported in part by NSF under Grant No. PHY99-0 7949

8:48AM A40.00005 Multiparticle interference, GHZ entanglement, and full counting statistics
, HEUNG-SUN SIM, Department of Physics, Korea Advanced Institute of Science and Technology, Daejeon 305-701, Korea, EUGENE V. SUKHORUKOV, Department of Theoretical Physics, University of Geneva, CH-1211 Geneva 4, Switzerland — We study [1] quantum coherent transport in a generalized N-particle Hanbury Brown-Twiss setup enclosing magnetic flux, where electrons are injected from N independent sources and collected in N distant detectors, and show that the N-th order cumulant of current cross correlations exhibits flux-dependent periodic Aharonov-Bohm (AB) oscillations, while there is no such oscillation in all the lower-order cumulants. The origin of the multiparticle interference is the orbital Greenberger-Horne-Zeilinger entanglement of N identical particles. For sufficiently strong AB oscillations the generalized N-particle Bell inequalities may be violated, proving the N-particle quantum nonlocality.
[1] H.-S. Sim and E. V. Sukhorukov, condmat/0508399.

9:00AM A40.00006 Correlations in a multi-qubit state
, D.L. ZHOU, School of Physics, Georgia Institute of Technology, Atlanta, Georgia 30332, USA, B. ZENG, Department of Physics, Massachusetts Institute of Technology, MA 02139, USA, Z. XU, Center for Advanced Study, Tsinghua University, Beijing 100084, China, L. YOU, School of Physics, Georgia Institute of Technology, Atlanta, Georgia 30332, USA — For an arbitrary partition of a multi-qubit system, we define a correlation measure, which is directly based on a series of multi-qubit correlation functions, to characterize the total correlation among different parts. As an instructive application of our correlation measures, we investigate the entanglement of graph states.

9:12AM A40.00007 Entanglement of overlapping systems and the breakdown of the tensor product
, MATTHEW LEIFER, Perimeter Institute for Theoretical Physics — Recent work on entanglement in the presence of superselection rules has shown that entanglement ought to be defined operationally, i.e. with respect to sets of local operations actually available to Alice and Bob rather than with respect to an arbitrary tensor product factorization of the state space. Usually Alice and Bob's local operations are assumed to commute, which is an appropriate assumption when their systems are well separated. In this talk I address the question of how far the usual formalism can be maintained if the local operations do not commute. This might be an appropriate description of the spin entanglement between two particles with overlapping spatial wavefunctions, since local operations might then have an effect on both spins. In this situation, the appropriate notion of entanglement is no longer associated to a tensor product factorization of the state space, but it can be approximated by one provided the overlap of the two systems is small and/or the preparable states are sufficiently mixed. In this talk I will present a simple model of the breakdown of the tensor product for two qubits, characterize the states that need to be prepared to observe the effect and discuss how the observed entanglement is related to the entanglement with respect to the usual tensor product factorization.

9:24AM A40.00008 Modelling Pauli measurements on arbitrary stabilizer states via local hidden variables assisted by classical communication
, MATTHEW ELLIOTT, BRYAN EASTIN, CARLTON CAVES, University of New Mexico, JONATHAN BARRETT, Perimeter Institute, STEFANO PIRONIO, California Institute of Technology — In this talk I present communication-assisted local-hidden-variable models for measurements of products of Pauli matrices on stabilizer states. Models are analyzed with respect to restrictions imposed and their efficacy in predicting overall measurement outcomes as well as outcomes of correlated subsets of measurements. In particular, I present a model in which the quantum mechanical results of Pauli product measurements can be predicted by a local-hidden-variable table supplemented by an efficient amount of classical communication and computation.

9:36AM A40.00009 Quantum Chaos, Localization, and Entanglement in Disordered Heisenberg Models

, WINTON BROWN, Dartmouth College, DAVID STARLING, SUNY Fredonia, LEA SANTOS, LORENZA VIOLA, Dartmouth College — We explore the relation between quantum chaos, localization, and entanglement in a two-dimensional disordered Heisenberg spin-1/2 system. Apart from the recent interest in such systems as models for proposed quantum computing architectures, they exhibit interesting transition regions from integrability to chaos and from higher to lower degree of symmetry. Complementing the standard eigenvalue-based analysis for identifying the cross-over into chaos, we suggest looking at the relative delocalization of eigenvectors related to different disorder realizations as a basis-independent indicator of chaoticity. We investigate the behavior of several measures of bipartite and multipartite entanglement – including concurrence; von Neumann entropy; and, using the framework of generalized entanglement, a family of local purities. Our results indicate that bipartite entanglement decreases in the chaotic region, whereas the opposite holds for multipartite entanglement. Connections are established with predictions from random matrix theory.

9:48AM A40.00010 Entanglement Scaling at Quantum Phase Transitions in Correlated Electron Systems

, DANIEL LARSSON, Philipps-Universität Marburg, Germany, HENRIK JOHANNESSON, Göteborg University, Sweden — We have carried out an analytic study of the entanglement scaling properties in the one-dimensional Hubbard model. We present exact scaling formulas for the local ("single-site") entanglement $\mathcal{E}$ at a quantum phase transition driven by a magnetic field or a chemical potential. The leading divergences of $d\mathcal{E}/dh$ and $d\mathcal{E}/d\mu$ are shown to be directly related to those of the zero-temperature spin and charge susceptibilities. Logarithmic corrections signal a change in the number of local states accessible to the system as it undergoes the transition. We show that the results for the leading divergences are generic, and follow from the scaling hypothesis that any local observable exhibits a singularity at a quantum phase transition. Illustrations from other strongly correlated electron systems are given, including the long-range Hubbard model in one dimension.

10:00AM A40.00011 Coherent Interaction of Spins Induced by Thermal Bosonic Environment.

, DENIS TOLKUNOV, DMITRY SOLENOV, VLADIMIR PRIVMAN, Clarkson University — We obtain the indirect exchange interaction between two two-state systems, e.g., spins, in a formulation that also incorporates the quantum noise that they experience, due to an environment of bosonic modes, for instance, phonons. We predict that for low enough temperatures the interaction is coherent over time scales sufficient to create entanglement, dominated by the zero-point quantum fluctuations of the environment. We utilize a perturbative approach to obtain a quantum evolution equation for the two-spin dynamics. The induced interaction is calculated exactly. We identify the time scales for which the spins develop and sustain entanglement for various spatial separations.

10:12AM A40.00012 Entanglement entropy of random quantum critical points with general spin

, JOEL MOORE, UC Berkeley, GIL REFAEL, California Institute of Technology — The bipartite entanglement at 1D critical points of a subsystem of N sites with the remainder is known to diverge as $\log N$, with a coefficient that is related to the central charge for conformally invariant critical points. It was recently shown that for a class of spin-half random critical points, there is also a logarithmic divergence with a coefficient that is universal and corresponds to an irrational "effective central charge." This talk discusses generalizations of this result to higher-spin chains, including the permutation-symmetric critical points found by Damle and Huse, using a combination of analytic and numerical real-space renormalization group methods. Higher-spin chains show numerous complications relative to the spin-half case, such as the introduction of ferromagnetic bonds; their study provides a stringent test of the conjectured c-theorem for central charges defined via entanglement entropy.

10:24AM A40.00013 Local Entanglement and Quantum Phase Transition in Spin Models[1]

, SHI-JIAN GU, Department of Physics and Institute of Theoretical Physics, The Chinese University of Hong Kong, Hong Kong, China, GUANG-SHAN TIAN, School of Physics, Peking University, Beijing 100871, China, HAI-QING LIN, Department of Physics and Institute of Theoretical Physics, The Chinese University of Hong Kong, Hong Kong, China — In this work, we study quantum phase transitions in both the one- and two-dimensional XXZ models with either spin S=1/2 or S=1 by a local entanglement We show that the behavior of E_v is dictated by the low-lying spin excitation spectra of these systems. Therefore, the anomalies of E_v determine their critical points. It reminds us the well-known fact in optics: The three-dimensional image of one subject can be recovered from a small piece of holograph, which records interference pattern of the reflected light beams from it. Similarly, we find that the local entanglement, which is rooted in the quantum superposition principle, provides us with a deep insight into the long-range spin correlations in these quantum spin systems. **References:** [1] S. Sachdev, *Quantum Phase Transitions* (Cambridge University Press, Cambridge, 2000). [2] Shi-Jian Gu, Guang-Shan Tian, and Hai-Qing Lin quant-ph/0509070

[1]This work is supported by RGC Projects CUHK 401703 and 401504 and by CNSF grant No. 90403003.

10:36AM A40.00014 Quantum Entanglement in a Spin Ladder with Ring Exchange[1]

, JUN-LIANG SONG, SHI-JIAN GU, HAI-QING LIN, Institute of Theoretical Physics and Physics Department, The Chinese University of Hong Kong, Hong Kong, China — In this paper we've studied entanglement properties of a spin ladder with ring exchange. Several entanglement properties, e.g. pair concurrence and block-block entanglement were obtained by exact diagonalization method. The relationship between the global phase diagram and ground-state quantum entanglement was investigated. It was shown that block-block entanglement of different block size and configurations manifests richer information of the system. It was also found that the block-block entanglement reaches its maximum or minimum at some QPT points which is also the high symmetry point. The temperature dependence of the entanglement properties is also investigated and it is shown that entanglement is suppressed by the temperature fluctuations and vanishes at some threshold temperatures.

[1]This work is supported by RGC Projects CUHK 401703 and 401504.

10:48AM A40.00015 Entanglement and dissipation in a quantum-dot array.

, LESVIA DEBORA CONTRERAS-PULIDO, Centro de Investigacion Cientifica y de Educacion Superior de Ensenada (CICESE), FERNANDO ROJAS, Centro de Ciencias de la Materia Condensada-UNAM, RAMON AGUADO, Condensed Matter Theory, ICMM, CSIC — Primarily motivated by quantum information theory, charge in quantum dots (QD) seems to be a promising candidate for implementation of qubits and entangled states [1]. We explore theoretically the dynamical formation of entangled states, including dissipative effects, of two parallel double QD uncoupled between them but strongly coupled to the same phonon thermal bath. The QD array is modeled with an extended Hubbard type Hamiltonian and dissipation is taken into account by using a polaron transformation to obtain the reduced density matrix of the system [2]. We find that it is possible to obtain entangled electronic states through a strong electron-phonon interaction, characterized by: Wootters' concurrence, charge distribution and probabilities for each Bell state as a function of relevant parameters (hopping, temperature, electron-phonon amplitude). The work is supported by DGAPA project IN114403 and CONACyT project 43673-F [1] Hichri et al., Phys.E 24,234 (2004) [2] Aguado and Brandes, Phys.Rev.Lett.92, 206601 (2004).

Monday, March 13, 2006 11:15AM - 12:39PM –

Session B40 TGQI DCMP: Topics in Quantum Foundations Baltimore Convention Center 343

11:15AM B40.00001 Bell's inequalities: derivation, violation, and implications

, LOUIS SICA, Naval Research Laboratory (Retired) — Cross-correlations among jointly present data sets satisfy the Bell inequality as a fact of mathematics. Violation of Bell's inequalities by data correlations obtained in independent trials of quantum mechanical correlation experiments shows that a wide-sense spatially stationary (in angle) process cannot account for the Bell cosine correlation. Since the correlations usually measured are cosinusoidal, at least one variable pair of those constrained by a Bell's inequality must have a correlation function different from the usual cosine in order to satisfy the inequality. When nonlocal information is used to construct correlations among real and counterfactual measurements, the correlation functions obtained are not all of the simple cosine form, and the set of correlations satisfies the Bell inequalities. Thus, the resulting correlations are not based on a wide-sense stationary process. The same conclusion holds for properly correlated experimental data. These considerations may be extended to the domain of well-known inequalities in probabilities that follow from the correlational inequalities upon assuming a simple symmetry condition. Such results imply that a proof of nonlocality based on Bell's inequality violation must use different reasoning from that used historically.

11:27AM B40.00002 Correlated observables in field theoretic terms: single- and multi-particle systems

, IAN DURHAM, Saint Anselm College — In recent years correlations between two degrees of freedom for a single particle have been experimentally demonstrated and further experiments have been suggested. This has presented a more direct test of non-contextuality. The results indicate that quantum mechanical entanglement is a more complex process than non-local theories generally suggest. The nature of both the single-particle and multi-particle entanglement processes suggest that perhaps a field theoretic solution is tenable where measurements actually transform the entire field.

11:39AM B40.00003 Differences between the Measurement Process and Schrödinger Evolution

, STEINER MICHAEL, NRL — An overview of the Measurement Problem is given and an argument is presented that reduces the measurement problem to a 2-qubit problem of entanglement. In current experiments, the measurement problem has not been a limitation on what can be predicted. If the problem were to continue to not be a limitation for all future experiments of interest, then the problem may be interesting from a philosophical perspective, but is not limiting in terms of physical predictions. However, the author will show examples to illustrate why this is not the case. Certain experiments would be incorrectly predicted if the measurement process were replaced by Schrödinger evolution. Hence understanding the reason for measurement is of primary interest. A new direction toward developing a comprehensive theory will be proposed.

11:51AM B40.00004 Inference of Schrödinger Equation from Classical-Mechanics Solution[1]

, JX ZHENG-JOHANSSON, IOFPR, SWE, P-I JOHANSSON, Uppsala Univ, SWE — We set up the classical wave equation for a particle formed of an oscillatory massless charge, traveling at velocity v in a potential $V(X)$ in a one-d box along X axis, and its electromagnetic waves $\{\varphi_p^j\}$ (as virtual or "hidden" processes) as: $[c^2 - \frac{V}{m}]\frac{\partial^2 \psi}{\partial X^2} = \frac{\partial^2 \psi}{\partial T^2}$ (1). Where $\psi = \sum \varphi_p^j$; $p = \mathit{incident}$ or *reflected*, $j = \dagger$ or $\ddagger$ for $\angle[c, v] = 0$ or π, c velocity of light, $M = m\sqrt{1-(v/c)^2} = \frac{h\Omega}{2\pi c^2}$ the particle's rest mass, $\frac{\Omega}{2\pi}$ wave frequency for $v = 0$, and h Planck constant. For $V =$const, Eq (1) has the plane wave solutions: $\{\varphi_p^j = C_1 e^{i(K^j X - \Omega^j T)}\}$; $K^j(j = \left\{{\dagger \atop \ddagger}\right\}) = \frac{K}{1 \mp v/c}$ is a Doppler-displaced wavevector; $\Omega^j = K^j c$. From $\sum \varphi_p^j$, we get a standing beat, or de Broglie phase wave for the particle total motion: $\psi = 4C_1 \cos(KX) e^{i(\Omega + \frac{\Omega_d}{2})T}\Psi$. Where $\Psi = C\sin(K_d X) e^{-i\frac{\Omega_d}{2}T}$ describes the particle motion, and $K_d = \sqrt{(K^\dagger - K)(K - K^\ddagger)} = (\frac{v}{c})K$ the de Broglie wavevector; $\Omega_d = vK_d$. For V varying, we get similarly a ψ and Ψ from sums of partial plane waves from all of infinitesimal $(X_i, X_i + \Delta X)$. We can in turn subtract (1) by itself but with $v = 0$, getting an equation for Ψ: $[-\frac{\hbar^2}{2M}\frac{\partial^2}{\partial X^2} + V(X)]\Psi = i\hbar\frac{\partial \Psi}{\partial T}$, which is equivalent to the Schrödinger equation. (The so represented QM invites not the so-called EPR paradox.)

[1]JXZJ & P-IJ, *Unification of Classical, Quantum and Relativistic Mechanics and the Four Forces*, Nova Science, NY, 2005; *Quantum Theory and Symmetries IV*, ed VK Dobrev, Heron Press, 2006.

12:03PM B40.00005 Aton, Relativity, and Quantum Mechanics

, ALFRED PHILLIPS, JR., Source Institute — In the mechanics of the Aton, we have shown that the Davisson-Germer experiments and other crystal based experiments can be modeled without recourse to particle-wave notions. We have also shown that the energy levels of the hydrogen atom and the helium atom can be calculated accurately with Atonic Mechanics, subject to the limits of three-body effects in the latter atom. Using the Aton concept, we now provide a way to unify Einstein's Relativity with what we commonly refer to as quantum mechanics. We note that entanglement is an intrinsic part of the mechanics of the Aton.

12:15PM B40.00006 Vortex Theory and Photon Acceleration Effect

, KONSTANTIN GRIDNEV, RUSSELL MOON, VICTOR VASILIEV — Using the principles of the Vortex Theory, it was theorized that when a photon encounters an electromagnetic field, both the velocity and the frequency of the photon will change. To prove this idea an experiment was devised using a laser interferometer and electromagnets. The electromagnets were arranged so that when the beam splitter divided the initial beam of laser light into two secondary beams; one of the two secondary beams passed back and forth between the magnets. With the DC current to the electromagnets turned off, the two beams formed an interference pattern on the target screen. When the current to the electromagnets was suddenly turned on, the pattern fluctuated wildly until the two beams again reached a quiescent state creating a stable pattern on the screen; when the current to the electromagnets was suddenly turned off, again the pattern fluctuated wildly until it reached a quiescent state forming the initial stable pattern on the screen. It was determined that this new effect was a phenomenon created by the changing frequency of the laser light whose velocity is increasing as it passes between the expanding electromagnetic field of the magnets. Because it is a new phenomenon in science revealing that the speed of light is not a constant but indeed can be varied.

12:27PM B40.00007 The classical – quantum border at 10^{11} Hz and Cosmic Microwave Background

, SIMON BERKOVICH, George Washington University — Findings of non-trivial anisotropy of CMB challenge current cosmology. Notably, this has been predicted by our model of the Universe – a cellular automaton with a rule of distributed fault-tolerant synchronization (http://arxiv.org/abs/astro-ph/0509743). This model yields spectrum of elementary 'quasi-particles' and fast operational background: 'action-at-the-distance' for gravitation, underlying mechanism for Bohm-Hilley's interpretation of quantum phenomena and holographic reference waves for biological information. Matter creation is accompanied with 'shock wave' and synchronization-desynchronization undulations of 10^{-11} sec that form CMB. Its structurization is due to eccentric observation, the 2.72^0K 'temperature' of black body spectrum is indicative of 10^{11}frequency. Quantum strangeness stems from multiplexing of synchronized and desynchronized stages resulting in sophisticated behavior at the former and loose motion at the latter. The relative stage durations are determined by placing in the Universe, and propagation front may impact large molecules depending on their orientation. Quantum and Life mysteries being interrelated, both can be affected by the border frequency. Millimeter waves cause biological effects neither by heating nor direct action, but as a trigger. Mesoscopic quantum phenomena, like, e.g. superconductivity, can be destroyed by 10^{11} Hz. Thus, there is a possibility for a 10^{11} Hz threshold in disrupting quantum entanglement through the suggested multiplexed machinery.

Monday, March 13, 2006 2:30PM - 5:30PM –

Session D40 TGQI DCMP: Focus Session: Foundations of Quantum Theory Baltimore Convention Center 343

2:30PM D40.00001 From Quantum Foundations to Quantum Gravity , LUCIEN HARDY, Perimeter Institute — Quantum theory is a probabilistic theory with fixed causal structure. General relativity is a deterministic theory with dynamic causal structure. It seems likely then that a theory of quantum gravity will be a probabilistic theory with dynamic causal structure. Work in the foundations of quantum theory provides insight into how to build a framework for such theories. In this way we can hope that insights coming from quantum foundations can guide us in constructing a theory of quantum gravity.

3:06PM D40.00002 Quantum Mechanics in Terms of Symmetric Measurements , CHRISTOPHER FUCHS, Bell Labs, Lucent Technologies — In the neo-Bayesian view of quantum mechanics that Appleby, Caves, Pitowsky, Schack, the author, and others are developing, quantum states are taken to be compendia of partial beliefs about potential measurement outcomes, rather than objective properties of quantum systems. Different observers may validly have different quantum states for a single system, and the ultimate origin of each individual state assignment is taken to be unanalyzable within physical theory—its origin, instead, comes from prior probability assignments at stages of physical investigation or laboratory practice previous to quantum theory. The objective content of quantum mechanics thus resides somewhere else than in the quantum state, and various ideas for where that "somewhere else" is are presently under debate. What is overwhelmingly agreed upon in this effort is only the opening statement. Still, quantum states are not Bayesian probability assignments themselves, and different representations of the theory (in terms of state vectors or Wigner functions or C*-algebras, etc.) can take one further from or closer to a Bayesian point of view. It is thus worthwhile thinking about which representation might be the most propitious for the point of view and might quell some of the remaining debate. In this talk, I will present several results regarding a representation of quantum mechanics in terms of symmetric bases of positive-semidefinite operators. I also argue why this is probably the most natural representation for a Bayesian-style quantum mechanics.

3:18PM D40.00003 Influence-free states on compound quantum systems , HOWARD BARNUM, Los Alamos National Laboratory, CHRISTOPHER FUCHS, Bell Laboratories, Lucent Technologies, JOSEPH RENES, Institüt für Theoretische Physik, Universität Erlangen, ALEXANDER WILCE, Dept. of Mathematical Sciences, Susquehanna University — Probability states for bipartite local measurements and correlations between local measurements are considered, in general and when the local systems behave quantum-mechanically. We review the facts that in general allowing local measurements conditional on classically communicated results from the other site imposes no-signalling in the direction opposite communication, and that in the locally quantum case, two-way no-signalling restricts states to be in the dual of the cone of unentangled states, isomorphic to that of positive maps. We show that in the "decomposable" subcone, generated by quantum states and their partial transposes, the extremal quantum states and extremal partial transposes remain extremal. And we show that decomposable states do not violate Cirelson inequalities. We show that locally-quantum no-signalling states must be combined in a thoroughgoing no-signalling fashion. Thus Alice and Bob cannot consistently accumulate a sequence of independent states of this nature (as they might a supply of shared Bell states to use in entanglement distillation) while having available the full panoply of quantum observables and operations at their respective sites. The relation of no-signalling to the "closest-to-Bayesian" conditional quantum dynamics of C. Fuchs will also be touched on.

3:30PM D40.00004 Liouville mechanics with an epistemic restriction and Bohr's response to EPR , TERRY RUDOLPH, Imperial College, STEPHEN BARTLETT, University of Sydney, ROBERT SPEKKENS, Perimeter Institute — We introduce a toy theory that reproduces a wide variety of qualitative features of quantum theory for degrees of freedom that are continuous. Specifically, we consider classical mechanics supplemented by a constraint on the amount of information an observer may have about the motional state (i.e. point in phase space) of a collection of classical particles – Liouville mechanics with an epistemic restriction (This may well be how Heisenberg initially understood the Uncertainty Principle). We develop the formalism of the theory by deriving the consequences of this "classical uncertainty principle" on state preparations, measurements, and dynamics. The result is a theory of hidden variables, although it is not a hidden variable model of quantum theory because of its locality and noncontextuality. Despite admitting a simple classical interpretation, the theory also exhibits the operational features of Bohr's notion of complementarity. Indeed, it includes all of the features of quantum mechanics to which Bohr appeals in his response to EPR. This theory demonstrates, therefore, that Bohr's arguments fail as a defense of the completeness of quantum mechanics.

3:42PM D40.00005 Negativity and contextuality are equivalent notions of nonclassicality , ROBERT SPEKKENS, Perimeter Institute for Theoretical Physics — An important problem in the foundations of quantum theory is the identification of the precise manner in which quantum theories differ from their classical counterparts. Two notions of nonclassicality that have been investigated intensively are: (1) negativity, that is, the necessity of negative values in real-valued representations of quantum states such as the Wigner representation, and (2) contextuality, that is, the impossibility of a hidden variable model of quantum theory wherein the representation of measurements is noncontextual (also known as the Bell-Kochen-Specker theorem). We shall argue for a particular way of generalizing and making precise both of these notions. With the refined versions of each in hand, it becomes apparent that they are in fact one and the same notion of nonclassicality. It follows that any proof of contextuality is also a proof of negativity and vice-versa.

3:54PM D40.00006 Epistemic Excess Baggage of Hidden Variable Theories , NICHOLAS HARRIGAN, TERRY RUDOLPH, Imperial College London — In Quantum Mechanics (QM) preparations of a system are represented by density operators acting on the associated Hilbert space. An ontological ('hidden' variable) model however, views preparations as being described by probability distributions (known as epistemic states) over a set of 'hidden' variables. We investigate restrictions on the efficiency of any such model of QM through studying its preparation contextuality, a property that one can prove to be possessed by ontological models. This property implies the existence of cases wherein more than one distinct epistemic state must be associated with a single density operator in order to correctly reproduce QM predictions. Traditional proofs of preparation contextuality have exhibited scenarios in which it can only be seen that an ontological model must associate more than one epistemic state with some density operator, the exact number being uncertain. We investigate the existence of upper or lower bounds on the number of distinct epistemic states that an ontological model must associate with density operators in order to reproduce QM statistics. The bounds obtained are yet another clue as to how one might quantify the non-classical nature of QM. We provide some speculation on how these results may shed light on the difficulty of simulating quantum mechanical systems on a classical computer.

4:06PM D40.00007 Pushing the Experimental Limits of Bell Inequalities , JOSEPH ALTEPETER, EVAN JEFFREY, PAUL KWIAT, University of Illinois at Urbana-Champaign — Using pairs of polarization-entangled photons, we report measurements of Bell's inequalities near the limits of physically allowable violations. As there are several methods by which one can judge the significance of a violation, we report the largest violation to date measured in both standard deviations (2417-sigma) and absolute size (2.826 +/- 0.005). These extremely precise and extremely non-classical results were obtained by carefully characterizing each experimental loss and inefficiency. Unfortunately, accounting for these losses and inefficiencies in the system requires auxiliary assumptions, assumptions which strictly fail to exclude local hidden variable models, and therefore also fail to rigorously test local realism. We therefore additionally report on progress towards a "loophole-free" test of Bell's inequality, whereby these experiemental losses and inefficiencies are virtually eliminated, and along with them, the need for auxiliary assumptions about the nature of the systems being measured.

4:18PM D40.00008 Can Two-photon Correlation of Chaotic Light Be Considered as Correlation of Intensity Fluctuations?[1] , GIULIANO SCARCELLI, VINCENZO BERARDI, YANHUA SHIH, University of Maryland, Baltimore County — Unlike first-order correlation, which is considered as a coherent effect of the electromagnetic field, the second-order correlation of radiation is considered as the classical statistical correlation of intensity fluctuations. The first second-order correlation experiment was demonstrated by Hanbury Brown and Twiss (HBT) stimulating a debate about the classical or quantum nature of the phenomenon. Although quantum models of HBT experiment have been attempted, the classical statistical interpretation has been widely accepted. The concept of intensity fluctuation has even been extended to quantum models: "photon bunching" is a phenomenological extension to quantum theory of the statistical correlation on photon number fluctuations. We argue that two-photon correlation phenomena, including HBT, have to be understood as a two-photon coherent effect: quantum interference between two-photon probability amplitudes. To do so, we present a "ghost" imaging experiment of chaotic light to show that the classical understanding in terms of intensity fluctuations does not give a correct interpretation for the observation. From a practical point of view, this experiment shows the possibility of having high contrast lensless two- photon imaging with chaotic light, suggesting imaging applications for radiations for which no effective lens is available.

[1]This research was supported in part by ARO and by NASA-CASPR.

4:30PM D40.00009 Predictability sieve, pointer states, and the classicality of quantum trajectories , DIEGO DALVIT, Los Alamos National Laboratory, JACEK DZIARMAGA, Jagelonian University, WOJCIECH ZUREK, Los Alamos National Laboratory — We study various measures of classicality of the states of open quantum systems subject to decoherence. Classical states are expected to be stable in spite of decoherence, and are thought to leave conspicuous imprints on the environment. Here these expected features of environment-induced superselection (einselection) are quantified using four different criteria: predictability sieve (which selects states that produce least entropy), purification time (which looks for states that are the easiest to find out from the imprint they leave on the environment), efficiency threshold (which finds states that can be deduced from measurements on a smallest fraction of the environment), and purity loss time (that looks for states for which it takes the longest to lose a set fraction of their initial purity). We show that when pointer states – the most predictable states of an open quantum system selected by the predictability sieve – are well defined, all four criteria agree that they are indeed the most classical states. We illustrate this with two examples: an underdamped harmonic oscillator, for which coherent states are unanimously chosen by all criteria, and a free particle undergoing quantum Brownian motion, for which most criteria select almost identical Gaussian states (although, in this case, predictability sieve does not select well defined pointer states.) Reference: D.A.R. Dalvit, J. Dziarmaga, and W.H. Zurek, Phys. Rev. A 72, 062101 (2005).

4:42PM D40.00010 Decoherence from Spin Environments , FERNANDO CUCCHIETTI, Los Alamos National Laboratory, JUAN PABLO PAZ, Universidad de Buenos Aires, WOJCIECH ZUREK, Los Alamos National Laboratory — We examine two exactly solvable models of decoherence – a central spin-system, (i) with and (ii) without a self–Hamiltonian, interacting with a collection of environment spins. In the absence of a self–Hamiltonian we show that in this model (introduced some time ago to illustrate environment–induced superselection) generic assumptions about the coupling strengths can lead to a universal (Gaussian) suppression of coherence between pointer states. On the other hand, we show that when the dynamics of the central spin is dominant a different regime emerges, which is characterized by a non–Gaussian decay and a dramatically different set of pointer states. We explore the regimes of validity of the Gaussian–decay and discuss its relation to the spectral features of the environment and to the Loschmidt echo (or fidelity).

4:54PM D40.00011 The Afshar Experiment and Complementarity , RUTH KASTNER, University of Maryland, College Park — A modified version of Young's experiment by Shahriar Afshar demonstrates that, prior to what appears to be a "which-way" measurement, an interference pattern exists. Afshar has claimed that this result constitutes a violation of the Principle of Complementarity. This paper discusses the implications of this experiment and considers how Cramer's Transactional Interpretation easily accomodates the result. It is also shown that the Afshar experiment is isomorphic in key respects to a spin one-half particle prepared as "spin up along x" and post- selected in a specific state of spin along z. The terminology "which way" or "which-slit" is critiqued; it is argued that this usage by both Afshar and his critics is misleading and has contributed to confusion surrounding the interpretation of the experiment. Nevertheless, it is concluded that Bohr would have had no more problem accounting for the Afshar result than he would in accounting for the aforementioned pre- and post- selection spin experiment, in which the particle's preparation state is confirmed by a nondestructive measurement prior to post-selection. In addition, some new inferences about the interpretation of delayed choice experiments are drawn from the analysis.

5:06PM D40.00012 Robust Weak Measurements , JEFF TOLLAKSEN, George Mason University, YAKIR AHARONOV, George Mason University, University of S. Carolina, and Tel Aviv University — We introduce a new type of weak measurement which yields a quantum average of weak values that is robust, outside the range of eigenvalues, extends the valid regime for weak measurements, and for which the probability of obtaining the pre- and post-selected ensemble is not exponentially rare. This result extends the applicability of weak values, shifts the statistical interpretation previously attributed to weak values and suggests that the weak value is a property of every pre- and post-selected ensemble. We then apply this new weak measurement to Hardy's paradox. Usually the paradox is dismissed on grounds of counterfactuality, i.e., because the paradoxical effects appear only when one considers results of experiments which do not actually take place. We suggest a new set of measurements in connection with Hardy's scheme, and show that when they are actually performed, they yield strange and surprising outcomes. More generally, we claim that counterfactual paradoxes point to a deeper structure inherent to quantum mechanics characterized by weak values (Aharonov Y, Botero A, Popescu S, Reznik B, Tollaksen J, Physics Letters A, 301 (3-4): 130-138, 2002).

5:18PM D40.00013 Quantum of Information , CASLAV BRUKNER, ANTON ZEILINGER, Institute of Experimental Physics, University of Vienna, Boltzmanngasse 5, 1090 Vienna, Austria — The violation of local realism is today a well established experimental fact. From it follows that either locality or realism or both cannot provide a foundational basis of Nature. Relaxing the locality condition would essentially not change the epistemological structure of classical physics but only extend its limits. Abandonment of reality, however, would require a radical revision of the conceptual background of all our theories so far. Is a novel conceptual basis of quantum theory feasible, in which the impossibility of defining external reality independent and prior to observation naturally emerges? We suggest the finiteness of information content of a quantum system as providing such basis. Any realistic theory that could arrive at an accurate prediction of a particular event would require the system to carry information as to which specific result will be observed for all possible future measurements. Because the system cannot carry more information than is in principle available, there must exist measurements for which individual events contain an element of irreducible randomness. Quantum entanglement arises from the possibility that information in a composite system resides more in the correlations than in properties of individuals. In the talk we will report on recent efforts towards providing derivations of the elements of the Hilbert space structure from the quantization of information.

Tuesday, March 14, 2006 5:30PM - 6:30PM –
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5:30PM L40.00001 TGQI Business Meeting –

Wednesday, March 15, 2006 11:15AM - 2:15PM –
Session P40 DCOMP TGQI: Focus Session: Pathways to Practical Quantum Computing I
Baltimore Convention Center 343

11:15AM P40.00001 Solid state technologies for quantum computers , DAVID DIVINCENZO, IBM Research Division — Impressive progress is now being made in realizing the rudiments of quantum computers in solid state devices. I will discuss two of them. First, single electron quantum dots now offer a higly coherent spin state for use as a qubit. Decoherence effects, arising from hyperfine interactions and the spin-orbit interaction, are well on their way to being understood and controlled. Second, Josephson junction devices, in many forms, are showing promise as qubits. The dynamics of these electric circuits can be designed to exhibit a wide variety of quantum effects; good two-level systems can be produced by careful design, and careful schemes for decoupling from the environment. Coupling to harmonic modes offer a wide variety of "quantum optic" realizations in the microwave regime.

11:51AM P40.00002 CNOT logic for Josephson phase qubits , MICHAEL GELLER, EMILY PRITCHETT, ANDREW SORNBORGER, University of Georgia, MATTHIAS STEFFEN, JOHN MARTINIS, University of California, Santa Barbara — Josephson junctions have demonstrated enormous potential as qubits for scalable quantum computing architectures. Here we study the speed and fidelity of four controlled-NOT gate implementations designed for capacitively coupled phase qubits. One gate applies to qubits fixed permanently in resonance, two require varying the dc current bias, and the fourth applies to permanently detuned qubits. Realistic simulations suggest that these implementations can be demonstrated with good fidelity using existing superconducting circuits.

12:03PM P40.00003 Violation of Bell's Inequality using Josephson Phase Qubits , MARKUS ANSMANN, R. BIALCZAK, N. KATZ, E. LUCERO, R. MCDERMOTT, M. NEELEY, M. STEFFEN, E.M. WEIG, A.N. CLELAND, J.M. MARTINIS, UC Santa Barbara — Recent improvements of the measurement visibility and coherence times in Josephson Phase Qubits have enabled first tests of two- qubit quantum gates and examination of quantum phenomena using these devices. Here, we present an experiment in which we attempt to violate Bells Inequality, which would be further proof that the system at hand behaves in a truly quantum mechanical way. The violation of Bells Inequality is the primary argument against the possible existence of a hidden- variable-theory as an alternative to quantum mechanics. This experiment illustrates the use of coherent control over capacitatively coupled qubits with always-on coupling, including the establishment of the system in eigenstates of the coupling, e.g. the singlet state. Single qubit rotations combined with a simultaneous, fast, high-visibility readout allow for state- tomography on the system.

12:15PM P40.00004 Experimental State Tomography using Superconducting Quantum Bits , M. STEFFEN, M. ANSMANN, R. BIALCZAK, N. KATZ, E. LUCERO, R. MCDERMOTT, M. NEELEY, E.M. WEIG, A.N. CLELAND, J.M. MARTINIS, UC Santa Barbara — The superconducting approach to building a scalable quantum computer has enjoyed tremendous successes in the past several years with coherence times now sufficiently long to implement quantum gates on a system with coupled qubits. In order to quantify the performance or fidelity of the gates, quantum state tomography is required. Successful state tomography relies on high measurement fidelities and the ability to perform arbitrary rotations in the transverse plane of the Bloch sphere. Here, we have made significant progress towards overcoming these challenges and present, for the first time, experimental data on single and two-qubit state tomography.

12:27PM P40.00005 Towards single shot read-out in circuit quantum electrodynamics (QED) , ANDREAS WALLRAFF, DAVID SCHUSTER, ALEXANDRE BLAIS, JAY GAMBETTA, LUIGI FRUNZIO, JOE SCHREIER, BLAKE JOHNSON, ANDREW HOUCK, WILL BRAFF, HANNES MAJER, MICHEL DEVORET, STEVE GIRVIN, ROB SCHOELKOPF, Depts. of Applied Physics and Physics, Yale University — In recent experiments we have demonstrated the resonant coherent coupling of individual photons to a single qubit implemented as a Cooper pair box in a high quality superconducting cavity [1]. In the non-resonant case, the dispersive coupling between the qubit and the cavity field is used to perform quantum non-demolition (QND) measurements of the qubit state [2]. Using this read-out technique we have performed high visibility measurements of Rabi oscillations and Ramsey fringes [3]. Here we present a detailed experimental and theoretical analysis of the cavity response for continuous and pulsed measurements in a wide range of cavity drive amplitudes. We also discuss an optimal read-out strategy for qubits in a continuous QND measurement and aim at demonstrating single shot read-out in the circuit QED architecture [4].

[1] A. Wallraff et al. Nature (London) 431, 162 (2004)
[2] D. I. Schuster et al. Phys. Rev. Lett. 94, 123602 (2005)
[3] A. Wallraff et al. Phys. Rev. Lett. 95, 060501 (2005)
[4] A. Blais et al. Phys. Rev. A 69, 062320 (2004)

12:39PM P40.00006 Coherent control in circuit QED , ALEXANDRE BLAIS, JAY GAMBETTA, ANDREAS WALLRAFF, DAVID SCHUSTER, LUIGI FRUNZIO, JOHANNES MAJER, STEVEN M. GIRVIN, ROBERT J. SCHOELKOPF, Yale University — Superconducting charge qubits fabricated inside a transmission line resonator have been used to successfully demonstrate strong interaction of an artificial atom with a single photon [1]. This architecture has also been used to show high-visibility and long coherence time ($T_1 \sim 7$ μs, $T_2 \sim 500$ ns) Rabi oscillations [2] and in the detailed study of measurement-induced dephasing [3]. Here we will discuss protocols to realize one and two-qubit logical gates in circuit QED. These are based on resonant and off-resonant irradiation of the transmission line resonator. First experimental results towards the realization of these gates will be presented. Supported by NSA and ARDA under ARO Contract No. W911NF-05-1-0365 and the NSF under Grants No. ITR-0325580 and No. DMR-0342157. [1] A. Wallraff *et al.*, Nature 431, 162 (2004). [2] A. Wallraff *et al.*, Phys. Rev. Lett., 95, 060501 (2005). [3] D. Schuster *et al.*, Phys. Rev. Lett., 94, 123602 (2005).

12:51PM P40.00007 Superconducting SET backaction on the Cooper-pair box , JOHANNES MAJER, BENJAMIN TUREK, Yale University, AASISH CLERK, McGill University, STEVEN GIRVIN, ROBERT SCHOELKOPF, Yale University, KEVIN BLADH, DAVID GUNNARSSON, PER DELSING, Chalmers Institue of Technology — We report on measurements of the backaction of a superconducting single electron transistor (SSET) measuring a Cooper-pair box qubit. During the weak, continuous measurement made by the SSET, the charge noise acts on the Cooper-pair box. The quantum nature of that noise is able to dephase, relax and even excite the qubit. This noise depends strongly on the operating point of the SSET. We operate the SSET near the double Josephson quasiparticle (DJQP) feature, where the backaction of the SSET is well understood (A. Clerk, et al., Phys. Rev. Lett. 89, 176804 (2002)), and where there are no quasiparticle poisoning effects. Measurements of the relaxation time of the Cooper- pair box reveal the symmetric component of the quantum noise and measurements of the steady-state polarization reveal the anti-symmetric component. Both measurements vary as expected with SSET operating point and confirm this model of SSET backaction.

1:03PM P40.00008 Information Flow in the Readout of a Superconducting Quantum Bit , I. SIDDIQI, R. VIJAY, M. METCALFE, E. BOAKNIN, C. RIGETTI, L. FRUNZIO, R. SHOELKOPF, M.H. DEVORET, Yale University — Quantum computation requires efficient and well controlled coupling between qubits. Superconducting qubits can be strongly coupled using passive electrical circuit elements, but one of the major remaining challenges is to eliminate uncontrolled coupling to parasitic degrees of freedom. I will present experimental results on charge qubits integrated with a novel readout device – the Josephson bifurcation amplifier (JBA). New experiments using the improved readout fidelity and speed of the JBA quantify parasitic losses and shed light on their mechanism.

1:15PM P40.00009 Mach-Zehnder-type Interferometry in a Strongly Driven Persistent-Current Qubit[1] , WILLIAM OLIVER, MIT Lincoln Laboratory, YANG YU[2], MIT EECS Department, JANICE LEE, MIT EECS Department, KARL BERGGREN, MIT EECS Department, LEONID LEVITOV, MIT Physics Department, TERRY ORLANDO, MIT EECS Department — We have demonstrated Mach-Zehnder-type interferometry with a niobium superconducting persistent-current qubit. The qubits ground and first-excited states exhibit an anti-crossing. Driving the qubit with a large-amplitude harmonic excitation sweeps it through this anti-crossing two times per period. The induced Landau-Zener (LZ) transitions act as coherent beamsplitters, and the accumulated phase between LZ transitions varies with the driving amplitude. We have observed quantum interference fringes as a function of the driving amplitude for 1 to 20 photon excitations. We present and discuss these results.

[1]This work at was supported by the AFOSR (F49620-01-1-0457) under the DURINT program and the DoD under Air Force contract FA8721-05-C-0002.
[2]present address: Nanjing University

1:27PM P40.00010 Double Quantum Dot Molecule Coupled with Single-Electron Transistors for Quantum Computation Applications[1] , LIMIN CAO, PHILLIP WU, FABIO ALTOMARE, A. M. CHANG, Department of Physics, Duke University, Durham, NC 27708, M. R. MELLOCH, School of Electrical Engineering, Purdue University, West Lafayette, IN 47907 — We describe the fabrication of a series-coupled double quantum dot (DQD) with side-coupled single-electron transistors (SETs). The DQD are intended to work as qubits, and the SETs perform the quantum spin measurements. The device was fabricated on a GaAs/AlGaAs heterostructure using a one-step, two-angle, evaporation of aluminum. Our design is compatible with modern semiconductor techniques, and if proven successful, can readily be scaled into larger integrated qubit systems with spin manipulation and measurement circuitry. Our preliminary experimental results indicate that both the QDs and SETs have single-electron tunneling behaviors with good reproducibility. We will report on progress towards the in-situ detection of the spin and charge of a single electron trapped in the semiconductor quantum dots.

[1]Research supported in part by NSF DMR-0401648

1:39PM P40.00011 Charge fluctuation induced dephasing of exchange coupled spin qubits[1] , XUEDONG HU, University at Buffalo, SUNY, S. DAS SARMA, University of Maryland — Exchange coupled *spin* qubits in semiconductor nanostructures are shown to be vulnerable to dephasing caused by *charge noise* invariably present in the semiconductor environment. This decoherence of exchange gate by environmental charge fluctuations arises from the fundamental Coulombic nature of the Heisenberg coupling, and presents a serious challenge to the scalability of the widely studied exchange gate solid state spin quantum computer architectures. We explore the properties of the resulting exchange gate errors, and estimate dephasing times for coupled spin qubits in a wide range (from 1 nanosecond up to more than 1 microsecond) depending on the exchange coupling strength and its sensitivity to charge fluctuations in a particular nanostructure.

[1]We acknowledge support by NSA, LPS, and ARO.

1:51PM P40.00012 Solid-state quantum teleportation between nanomechanical modes , L. TIAN, S. M. CARR, National Institute of Standards and Technology, 100 Bureau Drive, Stop 8423, Gaithersburg, MD 20899 — We study a quantum teleportation scheme between two nanomechanical modes without local interaction. The nanomechanical modes are connected by and linearly coupled to the continuous variable modes of a superconducting circuit made of transmission line and Josephson junctions. The phase sensitive measurement during the teleportation can be conducted by a superconducting single electron transistor operated as an rf mixer. Using a Wigner function approach, we calculate the fidelity of transferring coherent state under finite temperature and non-unit detector efficiency. We show that a fidelity above the classical limit of $1/2$ can be achieved for a large range of parameters.

2:03PM P40.00013 Spin transport and quasi 2D architectures for donor-based quantum computing , AUSTIN FOWLER, Institute for Quantum Computing, University of Waterloo, Canada, LLOYD HOLLENBERG, ANDREW GREENTREE, CAMERON WELLARD, ARC Centre of Excellence for Quantum Computer Technology, University of Melbourne, Australia — The original Kane quantum computer architecture is based on a single line of ^{31}P atoms spaced a few tens of nm apart in an isotopically pure ^{28}Si lattice with electrodes above and between donor atoms. This architecture suffers from major technical issues including strong spatial oscillations in the nearest neighbour donor electron exchange coupling strengths at the scale of a single lattice site and an inability to limit the effect of a given electrode to its nearest donor or donor pair. Through the introduction of a new donor electron spin transport mechanism, a 2D donor electron spin quantum computer architecture is proposed. This new architecture addresses the exchange coupling and cross-talk issues, as well as a host of other physical barriers to implementation.

Wednesday, March 15, 2006 2:30PM - 5:30PM –

Session R40 DCOMP TGQI: Focus Session: Pathways to Practical Quantum Computing II

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2:30PM R40.00001 Liquid NMR quantum computations , RAYMOND LAFLAMME, Department of Physics, University of Waterloo — This abstract was not received electronically.

3:06PM R40.00002 Generating Spin Echoes in Dipolar Solids with π-Pulses: More is Different , DALE LI, Yale University Department of Physics, YANQUN DONG, Yale University Department of Physics, RONA RAMOS, Yale University Department of Physics, ANATOLY DEMENTYEV, Yale University Department of Physics, SEAN BARRETT, Yale University Department of Physics — NMR spin echo measurements of ^{13}C in C_{60}, ^{89}Y in Y_2O_3, and ^{29}Si in Silicon are shown to defy conventional expectations when more than one π-pulse is used. Multiple π-pulse echo trains may either freeze-out or accelerate the dipolar decay of the signal, depending upon π-pulse phase, which suggests a connection to quantum dynamical decoupling and the formation of quantum Zeno subspaces. Exact quantum calculations (without a spin bath) reveal an intrinsic cause for these coherent phenomena: the dipolar coupling has a many-body effect during any real, finite pulse.

3:18PM R40.00003 From Large to Small Spin Systems: Exploring Many-body Effects in NMR

, YANQUN DONG, Department of Physics, Yale University, DALE LI, Department of Physics, Yale University, RONA RAMOS, Department of Physics, Yale University, SEAN BARRETT, Department of Physics, Yale University — NMR multi-pulse spin echo measurements on different nuclei and different samples show a dramatic Pulse Sequence Sensitivity (PSS): the multiple pi-pulse echo trains may either freeze out or accelerate the dipolar decay of the signal depending upon pi pulse phase. Finite-pulse spin simulations on small spin systems (7 spins) also show a tiny PSS. We propose that the dramatic PSS in experiments may be due to many-body effects during the finite pi pulses. If this is the case, the PSS should be less in small spin systems. This idea can be tested by performing spin echo experiments on small spin systems. The liquid crystal 5CB has a nematic phase, which enables the molecules to act like isolated spins systems in NMR. Since each molecule has 19 ^{1}H spins, this is an attractive system for our test. I will present experimental results on 5CB, and discuss their implication on our model.

3:30PM R40.00004 Observation of Anomolously Long-Lived Spin Echoes in a Dense Dipolar Spin System

, RONA RAMOS, YANQUN DONG, DALE LI, SEAN BARRETT, Yale University, Department of Physics — Continuing the investigation of anomolously long-lived spin echoes found in multipulse ^{29}Si NMR experiments, similar proton NMR experiments were performed on adamantane ($C_{10}H_{16}$, a molecular solid that tumbles about its fcc lattice sites). In contrast to the dilute dipolar silicon samples from previous experiments [A.E. Dementyev, D. Li, K. MacLean, S.E. Barrett, Phys. Rev. B 68, 153302 (2003).], adamantane presents a densely populated, strongly coupled proton spin system in which to probe the basis of this puzzle. Despite these changes, this phenomenon, which defies conventional NMR theory, still remains. This talk will discuss the results of these experiments and its impact on our current understanding of this behavior.

3:42PM R40.00005 Numerical modeling of the central spin problem using the spin coherent states P-representation

, V.V. DOBROVITSKI, Ames Laboratory and Iowa State University, Ames IA 50011, K.A. AL-HASSANIEH, E. DAGOTTO, Oak Ridge National Laboratory, Oak Ridge TN, and University of Tennessee, Knoxville TN 37831, B.N. HARMON, Ames Laboratory and Iowa State University, Ames IA 50011 — We analyze decoherence of a central spin coupled to a spin bath (the central spin problem). Theoretical understanding of this process is important for many experiments, such as the recent study of decoherence of the electron spin by the nuclear spins in a quantum dot. To investigate the important non-perturbative decoherence regimes, we developed an efficient mean-field-based method for modeling the spin-bath decoherence. The method is based on the P-representation for the central spin density matrix, which is very useful in quantum optics, but has not been widely applied to quantum many-spin systems. In contrast with the standard time-dependent mean field theory, our method gives excellent agreement with the exact solution. We demonstrate performance of the method for longitudinal and transversal relaxation at different external fields. In particular, by modeling the quantum systems with up to 16000 bath spins, we make controlled predictions for the slow long-time decoherence of the central spin. We thank L. Glazman, M. Lukin, A. Polkovnikov, and J. Taylor for helpful discussions. This work was supported by NSA, ARDA, ARO, and NSF.

3:54PM R40.00006 The sensitive electrical detection of spin coherence with pulsed electrically detected magnetic resonance

, CHRISTOPH BOEHME, University of Utah, Physics Department, 115 S 1400 E Suite 201, Salt Lake City, Utah 84112-0830, USA, KLAUS LIPS, Hahn-Meitner-Institut Berlin, Abteilung Siliziumphotovoltaik, 12489 Berlin, Germany — We present a pulsed electrically detected magnetic resonance experiment which allows the very sensitive observation of the coherent evolution of localized electron spins in semiconductors. The experiment takes advantage of spin selection rules of electronic transport transitions which exist for tunneling through localized states of a 20 nm thick disordered silicon buffer layer between a crystalline silicon wafer and an 80 nm thick ZnO surface layer. When coherent spin states of defect pairs are prepared by means of pulsed electron spin resonance, the singlet content (= the projection of density matrix onto the singlet state) of these states is directly proportional to the additional charge which is transmitted by the interface. Experimental data and the sensitivity limits of this spin measurement technique will be presented. The applicability of this for the readout of silicon based spin quantum information concepts is discussed.

4:06PM R40.00007 Polarization Requirements for Ensemble Implementations of Quantum Algorithms with a Single Bit Output

, BRANDON ANDERSON, University of Texas at Dallas, DAVID COLLINS, Bucknell University — We compare the failure probabilities of ensemble implementations of quantum algorithms which use pseudo-pure initial states, quantified by their polarization, to those of competing classical probabilistic algorithms. Specifically we consider a class algorithms which require only one bit to output the solution to problems. For large ensemble sizes, we present a general scheme to determine a critical polarization beneath which the quantum algorithm fails with greater probability than its classical competitor. We apply this to the Deutsch-Jozsa algorithm to determine the critical polarization.

4:18PM R40.00008 Optimizing quantum gate fidelities using energy-optimal control[1]

, SONIA SCHIRMER, Univ. of Cambridge — Optimal control theory offers a promising framework for optimizing essential tasks in quantum computing from quantum state preparation to the implementation of quantum gates. It is applicable to a wide variety of systems from atoms and ions to quantum dots, different control mechanisms from all-optical to all-electronic, and allows implementation constraints and dissipation to be accommodated. Most existing approaches focus on the exact implementation of (unitary) quantum gates in a particular model and aim to optimize gate operation times subject to certain assumptions such as arbitrarily fast local operations, weak (inter-qubit) coupling and decoherence, etc. We consider a different paradigm for optimal control focussing on optimizing the overall gate fidelity for a desired gate and fixed gate operation time subject to physical and experimental contraints (including dissipative effects), which may be more appropriate for some systems such as electronically-controlled systems with non-weak, always-on inter-qubit coupling. We discuss the basic framework and illustrate the results using calculations for model systems.

[1] This work was supported by the Cambridge MIT Institute.

4:30PM R40.00009 Exact solution of qubit decoherence models by a transfer matrix method.

, DIU NGHIEM, UW-Madison, ROBERT JOYNT, UW-Madison, QUANTUM COMPUTING UW-MADISON TEAM — A new method for the solution of the behavior of an enesemble of qubits in a random time-dependent external field was found. In this method the forward evolution in time is governed by a transfer matrix whose eigenvalues determine the various decoherence times. The method provides an exact solution in cases where the noise is piecewise constant in time. It can apply to a realistic model of decoherence of electron spins in semiconductors as well. Results are obtained for the non-perturbative regimes of the models, and we see a transition from weak relaxation to overdamped behavior as a function of noise anisotropy.

4:42PM R40.00010 Quantum kinetics of dynamical decoupling , LEONID P. PRYADKO, University of California, Riverside, PINAKI SENGUPTA, University of Southern California — In an ideal world, coherent control could be made perfect by running infinitely fast sequences of infinitely short pulses. In practice, in each system there are obvious spectral limitations. There is also a large-time limit set by decoherence due to environment coupling. Altogether, this makes pulse shape and sequence design an extremely complicated optimization problem. A systematic way to approach this problem is to consider a cumulant expansion of the evolution operator, treating the strong control fields exactly. The cumulants give the expansion of the effective Hamiltonian in powers of the system Hamiltonian. The locality of the cumulant expansion ensures that the classification by sequence order remains meaningful even for large systems. The corresponding calculation can be done efficiently by constructing a time-dependent perturbation theory expansion on small clusters [1]. Intuitively, refocusing should also remain effective in the presence of low-frequency environment, as long as the parameters of the system Hamiltonian are varying slowly compared to the refocusing period τ. A systematic study of this effect will be presented, based on the Floquet analysis of the non-Markovian quantum kinetic (master) equation for the open multi-qubit system in the presence of continuous refocusing fields exact up to 2nd order in the cumulant expansion [2]. [1] P. Sengupta and L. P. Pryadko, Phys. Rev. Lett. **95**, 037202 (2005). [2] L. P. Pryadko and P. Sengupta, quant-ph/0510001 (2005).

4:54PM R40.00011 Enhanced Convergence and Robust Performance of Randomized Dynamical Decoupling , LEA SANTOS, LORENZA VIOLA, Dartmouth College — Dynamical decoupling methods consist of repetitive sequences of control operations, whose net effect is to coherently modify the natural target dynamics to a desired one. In addition to standard deterministic schemes, randomized decoupling strategies have been recently introduced. Here, we exhibit clear evidence of the benefits of randomization in reducing the effects of undesirable couplings. For control systems which are either time-varying or require decoupling cycles involving a large number of operations, we find that simple randomized protocols offer superior convergence and stability as compared to high-level deterministic designs, including combinatorial and concatenated methods. We also show how significant improvements may be achieved for long interaction times by combining deterministic and stochastic features into new hybrid decoupling schemes.

5:06PM R40.00012 Resurrection of Schrödinger Cat , JAE-SEUNG LEE, ANATOLY KHITRIN, Department of Chemistry, Kent State University, Kent, Ohio 44242-0001 — The most striking difference between quantum and classical systems is the ability of quantum objects to be in a superposition state. A system in a superposition of macroscopically distinct states (*alive* and *dead* states of the "Schrödinger cat") would demonstrate highly unusual behavior. Cat states are the central elements in recent proposals on high-precision spectroscopy, amplified quantum detection and measurement. Quantum decoherence is the major obstacle in building practical devices which could revolutionize high-precision measurements or information processing. Here we experimentally demonstrate that quantum state of a system can be recovered after the state is destroyed by uncontrollable natural decoherence. The physical system used in this experiment is a cluster of seven dipolar-coupled nuclear spins of single-labeled ^{13}C-benzene oriented in liquid crystal. After decoherence of the cat state, superposition of states with all spins up (*alive*) and all spins down (*dead*), information stored in a single ancillary spin (^{13}C) is used to bring the protons subsystem into the *alive* state, while the excess entropy produced by decoherence is transferred to the ancillary spin.

5:18PM R40.00013 Statistical performance of ensemble quantum computers in search algorithms , DAVID COLLINS, TOMASZ KOTT, Physics and Astronomy Department, Bucknell University — We consider the statistical performance of ensemble quantum computers applied to search algorithms. In particular we consider algorithms implemented on pseudo pure initial states and determine the initial polarization required so that the quantum algorithm outperforms classical probabilistic competitors in terms of failure probabilities.

Thursday, March 16, 2006 8:00AM - 11:00AM –

Session U40 DCOMP TGQI DAMOP: Focus Session: Pathways to Practical Quantum Computing III Baltimore Convention Center 343

8:00AM U40.00001 Ion traps and cold atoms for quantum computers , IGNACIO CIRAC[1], Max-Planck Institute for Quantum Optics — Atoms can be used to store and manipulate quantum information. In particular, their internal state can be considered to form a register, and they can also be manipulated using laser light. In the case of trapped ions, the Coulomb force gives the required interaction to perform two-qubit gates. For neutral atoms, cold collisions can be used for that purpose. During the last years there has been an extraordinary experimental progress with those systems, and it is now possible to perform simple quantum information tasks with them. In this talk I will review several proposals for implementing quantum computers and quantum simulators using trapped ions and neutral atoms in optical lattices, and I will report on the latest experimental advances. Then, I will consider two particular aspects of those systems: (i) the possibility of simulating spin and bosonic systems with trapped ions; (ii) the possibility of performing quantum computations with neutral atoms without addressing them and in the presence of defects.

[1]Other authors (with same affiliation): Diego Porras, Karl Vollbrecht, and Enrique Solano

8:36AM U40.00002 Ion trap quantum computing with transverse phonon modes , SHI-LIANG ZHU, CHRIS MONROE, LUMING DUAN, Department of Physics, Michigan University — We propose a scheme to use the transverse modes to implement conditional phase gates on two trapped ions immersed in a large linear crystal of ions, without the sideband addressing. Comparing with the conventional approach using the longitudinal modes, with the cost that the laser power is slightly stronger, the proposed gate operation can be well inside Lamb-Dicke region and the gate infidelity due to the fluctuation of the effective Rabi frequency as well as the fundamental limits of the cooling procedure are approximately two orders smaller.

8:48AM U40.00003 Robust quantum memory using magnetic-field-independent atomic qubits[1] , C. LANGER, R. OZERI, J. D. JOST, B. DEMARCO[2], A. BEN-KISH[3], B. BLAKESTAD, J. BRITTON, J. CHIAVERINI, D. B. HUME, W. M. ITANO, D. LEIBFRIED, R. REICHLE, T. ROSENBAND, P. SCHMIDT, D. J. WINELAND — Scalable quantum information processing requires physical systems capable of reliably storing coherent superpositions for times over which quantum error correction can be implemented. We experimentally demonstrate a robust quantum memory using a magnetic-field-independent hyperfine transition in $^{9}Be^{+}$ atomic ion qubits at a field B = 0.01194 T. Qubit superpositions are created and analyzed with two-photon stimulated-Raman transitions. We observe the single physical qubit memory coherence time to be greater than 10 seconds, an improvement of approximately five orders of magnitude from previous experiments. The probability of memory error for this qubit during the measurement period (the longest timescale in our system) is approximately 1.4×10^{-5} which is below fault-tolerance threshold for common quantum error correcting codes.

[1]supported by DTO/NSA and NIST

[2]present address: University of Illinois, Urbana

[3]present address: Technion, Haifa, Israel

9:00AM U40.00004 Quantum logic in Group-II neutral atoms via nuclear-exchange interactions , DAVID HAYES, University of New Mexico, IVAN DEUTSCH, PAUL JULIENNE, NIST — The spin exchange-interaction generates an entangling quantum-logic gate, the square-root of SWAP, at the heart protocols employing single electron quantum dots. This is typically accompanied by strong Coulomb interactions and commensurate decoherence due to strong coupling of charge degrees of freedom to the noisy environment. We propose a protocol utilizing a *nuclear-exchange* interaction that occurs through ultracold collisions of identical spin 1/2 Group-II *neutral* atoms. A natural advantage is gained by storing the quantum information in nuclear spin states with long coherence times. Unlike NMR protocols based on weak magnetic dipole-dipole interaction, the nuclear exchange interaction stems from strong s-wave scattering of electrons. Nuclear exchange is ensured by the Fermi symmetry of the overall wave function. We have studied this protocol in the context of ^{171}Yb atoms trapped in far-off resonance optical dipole traps. Using quantum control analysis, high-fidelity operation is possible through controlled collisions in dynamically varied double-well trapping potentials.

9:12AM U40.00005 Quantum state reconstruction via continuous measurement , ANDREW SILBERFARB, IVAN DEUTSCH, University of New Mexico, GREG SMITH, POUL JESSEN, University of Arizona, Tucson — We present a new protocol for quantum state reconstruction based on weak continuous measurement of an ensemble average. This procedure applies the techniques of quantum control theory and quantum measurement theory to achieve a more efficient reconstruction than those performed using standard projective measurement techniques. This efficiency allows reconstruction of a quantum state using an single emsemble with minimal quantum backaction, setting the stage for state-based feedback control. An experimental demonstration of the technique will be presented in the context of reconstruction of the spin state of the F=3 hyperfine ground-state manifold of Cs-133 using continuous polarization spectroscopy.

9:24AM U40.00006 Quantum state control of atoms in microscopic optical traps[1] , MARK SAFFMAN, DENIZ YAVUZ, MARIE DELANEY, University of Wisconsin, PASAD KULATUNGA, Hobart and William Smith Colleges, TODD JOHNSON, ERICH URBAN, THOMAS HENAGE, NICHOLAS PROITE, THAD WALKER, University of Wisconsin — We present recent progress in loading and manipulation of neutral atoms in microscopic optical traps. Single Rb atoms are loaded into far off resonant optical traps from a background vapor of cold atoms. Tightly focused optical beams are used to perform two-photon stimulated Raman rotations between hyperfine qubit states. We demonstrate qubit rotations at a rate of 1.4 MHz, 1 ms coherence time, and individual site addressing with crosstalk at the level of 10^{-3}. These results are a significant step towards quantum computing using optically trapped neutral atoms. We discuss work in progress aimed at observing strong, angle independent dipole-dipole interactions for fast two-qubit gates using microwave dressing of Rydberg states. We demonstrate two-photon coherent excitation of Rydberg levels by a $5s_{1/2} - 5p_{3/2} - nd_{5/2}$ sequence. The possibility of dipole-dipole interactions without angular zeroes will be important for gates, as well as for coupling to mesoscopic qubits to enable transmission of quantum states.

[1]This work is funded by the NSF and the Army Research Office.

9:36AM U40.00007 Stochastic One-Way Quantum Computing with Ultracold Atoms in Optical Lattices , MICHAEL C. GARRETT, University of Calgary, DAVID L. FEDER, University of Calgary — The one-way model of quantum computation has the advantage over conventional approaches of allowing all entanglement to be prepared in a single initial step prior to any logical operations, generating the so-called cluster state. One of the most promising experimental approaches to the formation of such a highly entangled resource employs a gas of ultracold atoms confined in an optical lattice. Starting with a Mott insulator state of pseudospin-1/2 bosons at unit filling, an Ising-type interaction can be induced by allowing weak nearest-neighbor tunneling, resulting in the formation of a cluster state. An alternate approach is to prepare each spin state in its own sublattice, and induce collisional phase shifts by varying the laser polarizations. In either case, however, there is a systematic phase error which is likely to arise, resulting in the formation of imperfect cluster states. We will present various approaches to one-way quantum computation using imperfect cluster states, and show that the algorithms are necessarily stochastic if the error syndrome is not known.

9:48AM U40.00008 Generalized Coherent States via Markovian Decoherence , SERGIO BOIXO, University of New Mexico, Albuquerque, LORENZA VIOLA, Dartmouth College, GERARDO ORTIZ, HOWARD BARNUM, Los Alamos National Laboratory — Coherent states were introduced in the early days of quantum physics as 'quasiclassical' quantum states of an isolated quantum system. The decoherence program defines 'quasiclassical' (or 'pointer') states as states which are most stable in the presence of a coupling with the environment. Pointer states may be identified through the extremization of a 'predictability' functional on the Hilbert space. It has been known for some time that for the harmonic oscillator both concepts coincide under very generic conditions. Coherent states have been extended in the 70s to generalized coherent states. Recently, this approach has served as the basis to define generalized entanglement and conditions for quantum complexity. Here, we investigate the stability of generalized coherent states under Markovian open-system dynamics. In particular, we identify conditions under which generalized coherent states emerge as pointer states for systems described by algebras more general that the standard oscillator algebra. We present a streamlined method to find pointer states in the weak-coupling approximation, and discuss conditions for this approximation to be valid. We find that generalized coherent states and pointer states coincide under more restrictive conditions than the canonical, harmonic-oscillator coherent states. Finally, we address the connection of generalized coherent states to noiseless subspaces and subsystems.

10:00AM U40.00009 Generation of Werner states via collective decay of coherently driven atoms , KISHOR KAPALE, Jet Propulsion Laboratory, California Institute of Technology, GIRISH AGARWAL, Department of Physics, Oklahoma State University — We demonstrate deterministic generation of Werner states as a steady state of the collective decay dynamics of a pair of neutral atom coupled to a leaky cavity and strong coherent drive. We also show how the scheme can be extended to generate $2N$-particle analogue of the bipartite Werner states.

10:12AM U40.00010 Two-Qubit Quantum Computing using Pulsed ESR of N@C_{60} , GAVIN MORLEY, NHMFL, JOHAN VAN TOL, NHMFL, JINYING ZHANG, Materials Department, Oxford University, KYRIAKOS PORFYRAKIS, Materials Department, Oxford University, ARZHANG ARDAVAN, Clarendon Lab, Oxford University, ANDREW BRIGGS, Materials Department, Oxford University — N@C_{60} is a fullerene molecule containing an atom of nitrogen. The low-temperature decoherence time, T_2, can be increased to 215 μs, which is attractive for quantum information processing applications. The electronic and nuclear spins of the nitrogen atom are good quantum numbers in a strong magnetic field, coupled by the hyperfine interaction. Pulsed ENDOR (electron nuclear double resonance) can be used to initialize, manipulate and measure this two-qubit system. We used dynamic nuclear polarization (DNP) to prepare an initial state in which the nuclear and electronic spins were aligned with the applied field.

10:24AM U40.00011 Optimal control of logical operations in the presence of decoherence: A two-spin model , MATTHEW GRACE, CONSTANTIN BRIF, HERSCHEL RABITZ, Department of Chemistry, Princeton University, Princeton, NJ 08544, IAN WALMSLEY, Department of Physics, University of Oxford, Oxford OX1 3PU, UK, ROBERT KOSUT, SC Solutions, Inc., 1261 Oakmead Parkway, Sunnyvale, CA 94085, DANIEL LIDAR, Chemistry and Electrical Engineering Departments, University of Southern California, Los Angeles, CA 90089 — We study the feasibility of optimal control of logical operations in a simple model system composed of two interacting spins. In our model, one spin serves as a qubit and its evolution is controlled by a time-dependent external field. The other (uncontrolled) spin serves as an effective environment, coupling to which is a source of decoherence. The aim of control is to generate a target unitary operation for the qubit in the presence of the environmentally-induced decoherence. Given a target unitary operation G for the system, the fidelity of the actual transformation achieved is maximized with respect to the electric field $\epsilon(t)$ using two techniques, optimal control theory (OCT) and "pre-design" methods, which are well-developed in the field of nuclear magnetic resonance. The primary goal of this work is to illustrate the importance of OCT in designing logical operations, especially in the presence of environmental coupling, and the inadequacy of pre-designed gates in such situations.

10:36AM U40.00012 Rapid State-Reduction of Quantum Systems Using Feedback Control[1]

, JOSHUA COMBES, Griffith University, KURT JACOBS, Louisiana State University — Many potential applications of quantum devices, particularly in information processing, require quantum systems to be prepared in pure states. Due to environmental noise quantum systems often exist naturally in mixed states, and as a result a process of cooling or measurement must be used to purify them. In this work we consider the use of measurement for this purpose. The speed with which a measurement can purify, or reduce, the state of a quantum system is determined by the interaction between the system and measuring device, and places a limit on the speed of state-preparation. Here we consider using feedback control during the measurement to increase the rate of state-reduction. It was shown in [1] that for a single qubit this rate could be increased by a factor of 2. Here we show that for higher dimensional systems feedback control can provide a much larger speed-up. In particular, we show that for a measurement of an observable with N equally spaced eigenvalues, there exists a feedback algorithm which will increase the rate of state-reduction by a factor proportional to N. References: 1. K. Jacobs, Phys. Rev. A **67**, 030301(R) (2003). 2. J. Combes and K. Jacobs, Phys. Rev. Lett. (in press).

[1]We acknowledge support from the Australian Research Council and the State of Queensland

10:48AM U40.00013 Quantum Zeno stabilization in weak continuous measurement of two qubits

, RUSKO RUSKOV, Penn State University, ALEXANDER N. KOROTKOV, University of California, Riverside, ARI MIZEL, Penn State University — We have studied quantum coherent oscillations of two qubits under continuous measurement by a symmetrically coupled mesoscopic detector. The analysis is based on a Bayesian formalism that is applicable to individual quantum systems. Measurement continuously collapses the two-qubit system to one of the sub-spaces of the Bell basis. For a detector with linear response this corresponds to measurement of the total spin of the qubits. In the other extreme of purely quadratic response the operator $\sigma_y^1\sigma_y^2 + \sigma_z^1\sigma_z^2$ is measured. In both cases, collapse naturally leads to spontaneous entanglement which can be identified by measurement of the power spectrum and/or the average current of the detector. Asymmetry between the two qubits results in evolution between the different measurement subspaces. However, when the qubits are even weakly coupled to the detector, a kind of quantum Zeno effect cancels the gradual evolution and replaces it with rare, abrupt switching events. We obtain the asymptotic switching rates for these events and confirm them with numerical simulations. We show how such switching affects the observable power spectrum on different time scales.

Thursday, March 16, 2006 11:15AM - 2:03PM –

Session V40 TGQI DCMP: Focus Session: Linear Optics Quantum Computation Baltimore Convention Center 343

11:15AM V40.00001 High-fidelity linear optical quantum computing with polarization encoding

, FEDERICO SPEDALIERI, Jet Propulsion Laboratory, HWANG LEE, Lousiana State University, JONATHAN DOWLING, Louisiana State University — We show that the KLM scheme [Knill, Laflamme and Milburn, Nature **409**, 46] can be implemented using polarization encoding, thus reducing the number of path modes required by half. One of the main advantages of this new implementation is that it naturally incorporates a loss detection mechanism that makes the probability of a gate introducing a non-detected error, when non-ideal detectors are considered, dependent only on the detector dark-count rate and independent of its efficiency. Since very low dark-count rate detectors are currently available, a high-fidelity gate (probability of error of order 10^{-6} conditional on the gate being successful) can be implemented using polarization encoding. The detector efficiency determines the overall success probability of the gate but does not affect its fidelity. This can be applied to the efficient construction of optical cluster states with very high fidelity for quantum computing.

11:27AM V40.00002 Single Photon Source Using Chiral Nematic Liquid Crystal

, GANESH SELVARAJ, Louisiana State University, ANAND JHA, University of Rochester, PAVEL LOUGOVSKI, MARIAN FLORESCU, Louisiana State University, ROBERT BOYD, University of Rochester, JONATHAN DOWLING, Louisiana State University — With the development of Linear Optics Quantum Computing, a demand for a good single photon source has increased. Here we describe how a cholesteric liquid crystal can be used as a photonic band-gap material to design a single-photon source.We have a dipole embedded in a liquid crystal for which we find the spontaneous emission rate. We calculate the band structureof the cholesteric liquid crystal using the eigenfuncton expansion method and ultimately compute the density of modes. We also determine the field of the dipole embedded inside the cholesteric liquid crystal using the Green's function method from which we determine the spontaneous emmission rate.

11:39AM V40.00003 How to construct a Universal Linear Optical State Generator?

, PAVEL LOUGOVSKI, HWANG LEE, JONATHAN DOWLING, Louisiana State University — We consider all optical realization of a universal quantum state generator utilizing projective photon measurements to create an effective non-linearity. Specifically we are interested in finding a set of unitary optical devices required in order to generate a given quantum state for a given input and a projective measurement. We illustrate the formalism for a case of multi-photon path entangled states (N00N states). We conjecture an existence of necessary criteria connecting a size of a N00N state to a number of input modes of a generator.

11:51AM V40.00004 Towards one-way quantum computation with realistic devices

, TERRY RUDOLPH, Imperial College London — The one-way model seems particularly suited to certain proposed architectures for quantum computation, particularly those involving non-deterministic quantum gates. This talk will focus on strategies for dealing with faulty devices in the one-way model, particularly within the framework of linear optical quantum computation, although the results have more general significance. Special mention will made of strategies for dealing with faulty single photon sources and detectors, which are the primary experimental challenge for many proposed implementations of optical quantum computation.

12:27PM V40.00005 Single-photon sources for linear optics quantum computation

, TODD PITTMAN, BRYAN JACOBS, JAMES FRANSON, Johns Hopkins Univ. Applied Physics Laboratory, JOHNS HOPKINS UNIV. APPLIED PHYSICS LABORATORY TEAM — Although single-photon sources have recently been realized in a number of physical systems, only of few of them have experimentally demonstrated the types of properties required for linear optics quantum computing. In this talk, we review these requirements, and discuss the technical and fundamental challenges in meeting them. We will focus on a periodic source in which single-photons heralded from parametric down-conversion pairs are trapped and released from a storage loop.

12:39PM V40.00006 Optical Switches for Quantum Information Processing

, BRYAN JACOBS, Johns Hopkins University, TODD PITTMAN, JAMES FRANSON, Johns Hopkins University — Many of the basic components required for optical quantum computing and quantum communications have recently been demonstrated, including: single photon sources, quantum memories, logic operations, and photon number resolving detectors. Although the results of these proof-of-concept demonstrations are encouraging, errors in the current devices limit the range of applications to relatively small quantum circuits. The majority of the errors in the current devices originates from photon loss and decoherence in the switching elements. The single-photon nature of the signal, when coupled with quantum coherence requirements, limits the feasibility of using standard telecom switches in these applications. Here we discuss our recent work toward the development of optical switches specifically designed to accommodate the characteristics of photonic qubits.

12:51PM V40.00007 Entangled Photon Holes[1] , JAMES FRANSON, Johns Hopkins University — The probabilistic failure events of linear optics logic gates can be suppressed using the quantum Zeno effect enforced by strong two-photon absorption [1]. This would allow deterministic logic operations as a possible alternative to the use of cluster states. We have recently shown, however, that the rate of two-photon absorption can be substantially reduced by the generation of entangled photon holes that are analogous to the holes of semiconductor theory [2]. This reduction in the two-photon absorption rate is inconsistent with classical or semiclassical theory, and the entangled photon holes can violate Bell's inequality as well. As a practical matter, these difficulties can be avoided if the photons travel in opposite directions, in which case the entangled photon holes propagate away from each. The theory of entangled photon holes and their implications for the design of Zeno gates will be discussed.

1. J.D. Franson, B.C. Jacobs, and T.B. Pittman, Phys. Rev. A **70**, 062302 (2004).

2. J.D. Franson, submitted to Phys. Rev. Lett. (quant-ph/0510175).

[1]This work was supported by DTO and ARO.

1:03PM V40.00008 Creating single time-bin entangled photon pairs , CHRISTOPH SIMON, University of Grenoble (France), JEAN-PHILIPPE POIZAT, University of Grenoble — When a single emitter is excited by two phase-coherent pulses with a time delay, each of the pulses can lead to the emission of a photon pair, thus creating a "time-bin entangled" state. Double pair emission can be avoided by initially preparing the emitter in a metastable state. We show how photons from separate emissions can be made indistinguishable, permitting their use for multi-photon interference. Possible realizations with single atoms or ions and with quantum dots are discussed. The method might also allow the direct creation of n-photon entangled states (n>2).

1:15PM V40.00009 Towards a Quantum Memory for Photons in Erbium Doped Materials , SARA HASTINGS-SIMON, University of Geneva, MATTHIAS STAUDT, BARBARA KRAUS, WOLFGANG TITTEL, MIKAEL AFZELIUS, NICOLAS GISIN, University of Geneva, IGNACIO CIRAC, Max Planck Institute for Quantum Optics, MATTIAS NILSSON, STEFAN KROLL, Lund Institute of Technology — Quantum memories for single photons could play an important role in quantum communication and optical quantum computing. We present a proposal for the efficient storage and recall of photonic time-bin qubits, based on reversible absorption in a controllably broadened homogeneous absorption line. We report on the first experimental steps towards the realization of this quantum memory protocol. In particular, we have measured the homogenous lifetime of the relevant optical transition in erbium doped optical fibers and erbium doped lithium niobate waveguides by spectral hole burning and photon echo. We have also observed the controlled reversible broadening of spectral holes and spectral hole line shifts due to the Stark effect.

1:27PM V40.00010 Design of an on demand single photon source using a metal-insulator-semiconductor capacitor structure , B.H. HU, C.H. YANG, Department of Electrical and Computer Engineering, University of Maryland at College Park, M.J. YANG, Naval Research Laboratory — We propose an on-demand single photon source for unconditionally secure quantum cryptography. Similar to a typical metal-insulator-semicondoctor capacitor structure, the main component in the semiconductor is a p-doped quantum well, and the cylindrical gate under consideration is only nanometers in diameter. This MIS system can be biased to inversion, and, due to the small gate area, there are only a few electrons residing in a quantum dot at the onset of inversion. Considering the strong size quantization and large Coulomb energy, the number of electrons can be precisely controlled by the gate voltage. After holding just one electron in the inversion layer, the capacitor is quickly biased back to the flat band condition and the subsequent radiative recombination across the bandgap results in single photon emission. Using GaAs/AlAs as the model system, we present a numerical simulation of three-dimensional band bending and merits of this single photon source.

1:39PM V40.00011 Superconducting Bolometric Photon Detectors Using Epitaxial Niobium Thin Films , KEVIN M. INDERHEES, PAUL B. WELANDER, SEONGSHIK OH[1], JAMES N. ECKSTEIN, Department of Physics, Frederick Seitz Materials Research Laboratory, University of Illinois at Urbana-Champaign, Urbana, Illinois 61801 — Efficient single photon detection is a key part of optical qubit systems. We have made and tested superconducting bolometric photon detectors constructed from high quality epitaxial single crystal niobium films that are very flat. The devices operate at 4.2K and consist of narrow links which are current biased close to their critical current value. Absorption of a photon drives a portion of the device into the normal state, generating an observable voltage signal. The sensitivity is maximized when the link is biased near the critical current. The time averaged output voltage is linearly dependent on the optical power that illuminates the link. In order to optimize detector characteristics, we have studied the effects of changing the film thickness, the device geometry, and adding a protective cap.

[1]now at National Institute of Standards and Technology, Boulder, CO

1:51PM V40.00012 Quantum dots as a source of entangled photon pairs. , MARK STEVENSON, ROBERT YOUNG, Toshiba Research Europe Limited, PAOLA ATKINSON, KEN COOPER, DAVID RITCHIE, Cavendish Laboratory, University of Cambridge, ANDREW SHIELDS, Toshiba Research Europe Limited — Quantum dots are considered an attractive system for applications in quantum communication and quantum logic, confirmed by experimental demonstrations of quantum dot based single photon emission devices. Another key quantum optics resource is the on-demand generation of entangled photon pairs, for which the radiative decay of the biexciton state in a quantum dot has been proposed. The realization of such a device has been prevented due to polarization splitting of the exciton fine structure, caused by anisotropies of various structural parameters of the dot. We present the results of recent experiments that manage the splitting in quantum dots, in order to allow entangled photon emission. We demonstrate that dots with splitting within the homogeneous linewidth can be realized by carefully controlling the thickness of the dot layer. Furthermore, we show that the splitting can be reduced to zero by the application of an in-plane magnetic field. Polarization dependent correlation measurements on these dots will be presented that show characteristic features of entanglement, such as polarization correlation for all linear detection bases, and circular polarization anti-correlation. Our results indicate that for the first time, we have observed triggered entangled photon pair emission from a quantum dot.

Thursday, March 16, 2006 2:30PM - 5:30PM –

Session W40 TGQI DAMOP: Quantum Communication, Cryptography and Computation Baltimore Convention Center 343

2:30PM W40.00001 Quantum Communication via Frequency Upconversion[1] , AARON VANDEVENDER, PAUL KWIAT, University of Illinois at Urbana-Champaign — We describe a method for efficiently and coherently converting photonic qubits from one frequency to another for quantum communication. The conversion is done using quasi-phase-matched up-conversion in a Periodically Poled Lithium Niobate (PPLN) crystal. We have observed 99%-efficient and 95%-coherent conversion which allows faithful conversion of "flying" qubits to "stationary" qubits for use in quantum communication. We have also used up-conversion to prepare photons in arbitrary superpositions of widely separated frequency states, enlarging the accessible Hilbert space for communication of quantum states. Finally, we have seen 56%-efficient detection of 1550-nm photons using up-conversion to the visible and silicon Avalanche Photodiodes (APD), which would enhance the performance of quantum communication protocols (e.g., BB84) based on infrared (IR) photons over what is achievable with conventional IR single-photon detectors.

[1]This work was supported by the MURI Center for Photonic Quantum Information Systems (ARO/DTO program DAAD19-03-1-0199)

2:42PM W40.00002 Relativistic Quantum Cryptography , EVAN JEFFREY, PAUL KWIAT, University of Illinois at Urbana-Champaign — We present results from a relativistic quantum cryptography system which uses photon storage to avoid bit sifting, in principle doubling the useful key rate. Bob stores the photon he receives from Alice in an optical delay line until she sends him the classical basis information, allowing him to measure every photon in the correct basis. Accounting for loss in our 489-ns storage cavity, we achieve a 66% increase in the BB84 key rate. The same system could be used for even greater gains in either the six-state protocol or cryptography using a larger Hilbert space. We show that the security of this protocol is equivalent to standard BB84: assuming the quantum and classical signals are space-like separated, no eavesdropper bound by special relativity can access both simultaneously.

2:54PM W40.00003 Quantum Cryptography in Existing Telecommunications Infrastructure , DANIEL ROGERS[1], JOSHUA BIENFANG, ALAN MINK, BARRY HERSHMAN, ANASTASE NAKASSIS, XIAO TANG, LIJUN MA, DAVID SU, CARL WILLIAMS, CHARLES CLARK, National Institute of Standards and Technology — Quantum cryptography has shown the potential for ultra-secure communications. However, all systems demonstrated to date operate at speeds that make them impractical for performing continuous one-time-pad encryption of today's broadband communications. By adapting clock and data recovery techniques from modern telecommunications engineering practice, and by designing and implementing expeditious error correction and privacy amplification algorithms, we have demonstrated error-corrected and privacy-amplified key rates up to 1.0 Mbps over a free-space link with a 1.25 Gbps clock. Using new detectors with improved timing resolution, careful wavelength selection and an increased clock speed, we expect to quadruple the transmission rate over a 1.5 km free-space link. We have identified scalable solutions for delivering sustained one-time-pad encryption at 10 Mbps, thus making it possible to integrate quantum cryptography with first-generation Ethernet protocols.

[1]also with the University of Maryland Chemical Physics Program

3:06PM W40.00004 Alternative Design for Quantum Cryptographic Entangling Probe , HOWARD BRANDT, U.S. Army Research Laboratory — An alternative design is given for an optimized quantum cryptographic entangling probe for attacking the BB84 protocol of quantum key distribution [1], [2]. The initial state of the probe has a simpler analytical dependence on the set error rate to be induced by the probe than in the earlier design. The new device yields the same maximum information to the probe for a full range of induced error rates. As in the earlier design, the probe contains a single CNOT gate which produces the optimum entanglement between the BB84 signal states and the correlated probe states.
[1] H. E. Brandt, Phys. Rev. A **71**, 042312 (2005).
[2] H. E. Brandt, "Design for a quantum cryptographic entangling probe," to appear in J. Mod. Optics (2005).

3:18PM W40.00005 $\pi/3$ Phase-Shift Quantum Searching , LOV GROVER, Bell Labs, Lucent Technologies — Quantum searching normally consists of an alternate sequence of selective inversion and diffusion operations. The algorithm has been extensively studied and is well understood. However, there was a surprising result that was discovered last year. According to this, if we change the selective inversions to $\pi/3$ phase shifts and adjust the sign of the phase shift in a prescribed manner, we obtain an algorithm that converges monotonically towards the solution [1]. This is in contrast to the well-known search algorithm that has an oscillatory character. This leads to a number of new and interesting applications. For example, if we consider a situation where the probability of getting a target state for a random item, is $1-\epsilon$ (with ϵ unknown), then the probability of getting a target state after a single query in the new algorithm, can be increased to $1-\epsilon^3$, classically this can be increased to only $1-\epsilon^2$. The performance of the new algorithm has recently been proved to be optimal. Another important application of this technique is in correction of systematic errors [2].
References -
(1) L.K. Grover (2005), Fixed-point quantum search, Phys. Rev. Letters, Oct. 3, 2005.
(2) B.W. Reichardt and L.K. Grover, Quantum error correction of systematic errors using a quantum search framework, Phys. Rev. A, Oct. 25, 2005

3:30PM W40.00006 Relativistic Connection of Continuous and Discrete Quantum Walks , FREDERICK STRAUCH, National Institute of Standards and Technology — Quantum algorithms, based on a quantum-mechanical generalization of random walks, have been shown to be very effective at solving local search problems. These quantum walks come in two very different forms (discrete and continuous-time) with surprisingly similar properties. An open problem has been to identify just what makes these two walks so similar. In this talk I present the analytical connection of these two walks, by way of an analogy with properties of the Dirac equation, including entanglement, zitterbewegung, and most importantly, relativistic wave-packet spreading.

3:42PM W40.00007 Mixing and Decoherence in Continuous-Time Quantum Walks , LEONID FEDICHKIN, DMITRY SOLENOV, CHRISTINO TAMON, Clarkson University, VLADIMIR PRIVMAN, Clarkson University — We present analytical results showing that decoherence can be useful for speed-up of mixing in a continuous-time quantum walks on finite cycles. Our treatment of continuous-time quantum walks includes a continuous monitoring of all vertices that induces the decoherence process. We identify the dynamics of the probability distribution and observe how mixing times undergo the transition from quantum to classical behavior as our decoherence parameter grows from zero to infinity. Our results show that, for small rates of decoherence, the mixing time improves linearly with decoherence, whereas for large rates of decoherence, the mixing time deteriorates linearly towards the classical limit. In the intermediate region of decoherence rates, our numerical calculations confirm the existence of a unique optimal rate for which the mixing time is minimized.

3:54PM W40.00008 Decoherence by Correlated Noise and Quantum Error Correction[1] , EDUARDO NOVAIS, HAROLD U. BARANGER, Duke University — We study the decoherence of a quantum computer in an environment which is inherently non-Markovian and spatially correlated. We first derive the non-unitary time evolution of the computer and environment in the presence of a stabilizer error correction code. Our results demonstrate that effects of long-range correlation can be systematically reduced by suitable changes in the error correction codes. The new element that we discuss is that the periodic measurements in the QEC method separate the environmental modes into high and low frequencies. This natural "new" scale can then be used to better engineer quantum codes. As an example of this general discussion, we study decoherence in a quantum memory protected by Steane's three qubit code. The memory interacts with a bosonic enviroment through the spin-boson Hamiltonian. We calculate explicitly the long-range correlations in this case and demonstrate that a simple change in Steane's code reduces their effect.

[1] This work was supported in part by (1) the NSA and ARDA under ARO contract DAAD19-02-1-0079 and (2) the NSF Grant No. CCF-0523509.

4:06PM W40.00009 Topological Quantum Computing with Only One Mobile Quasiparticle , STEVEN H. SIMON, Lucent Technologies, Bell Labs, NICK BONESTEEL, Dept Physics and NHMFL, Florida State University, MICHAEL FREEDMAN, Microsoft Research, LAYLA HORMOZI, Dept Physics and NHMFL, Florida State University, NADA PETROVIC, UC Santa Barbara — In a topological quantum computer, universal quantum computation is performed by dragging quasiparticle excitations of certain two dimensional systems around each other to form braids of their world lines in 2+1 dimensional space-time. We show that any such quantum computation that can be done by braiding n identical quasiparticles can also be done by moving a single quasiparticle around $n-1$ other identical quasiparticles whose positions remain fixed. This result may greatly reduce the technological challenge of realizing topological quantum computation.

4:18PM W40.00010 CNOT for Fibonacci anyons with only one mobile quasiparticle[1] , LAYLA HORMOZI, GEORGIOS ZIKOS, NICK BONESTEEL, Dept. of Physics and NHMFL, Florida State University, STEVEN H. SIMON, Bell Laboratories, Lucent Technologies — Certain two-dimensional systems with non-abelian quasiparticle excitations can be used for topological quantum computation (TQC). In TQC qubits are encoded using 3 or 4 quasiparticles and quantum gates are carried out by braiding quasiparticle world lines. We focus on the problem of finding explicit braiding patterns that yield a universal set of quantum gates, using Fibonacci anyons — quasiparticles which are thought to exist in an experimentally observed fractional quantum Hall state at filling fraction $\nu = 12/5$. In previous work[2] we have shown how to construct arbitrary controlled rotation gates (which together with single qubit gates provide a universal set of quantum gates) by moving a pair of quasiparticles from the control qubit around the quasiparticles in the target qubit while keeping the latter at fixed positions. In this talk we show how to take advantage of one of the structural properties of Fibonacci anyons (namely the fusion matrix) to construct a certain class of two-qubit gates (including CNOT) with only *one* mobile quasiparticle — therefore reducing the number of braiding operations by a factor of two.

[1]This work is supported by US DOE grant DE-FG02-97ER45639.
[2]N.E. Bonesteel, L. Hormozi, G. Zikos, and S. H. Simon, Phys. Rev. Lett. **95**, 140503 (2005).

4:30PM W40.00011 Quantum Phase Transitions and Typical Case, Polynomial Time Solution of Randomly Generated NP-Complete Problems via Adiabatic Quantum Computation[1] , WILLIAM KAMINSKY, SETH LLOYD, MIT — We argue theoretically that adiabatic quantum computation using only polynomial resources can solve almost all members of a nontrivial randomly generated set of NP-complete problem instances, namely the problem of finding the ground states of spin glasses on 3D cubic lattices having independent, identically Gaussian-distributed couplings. The argument uses the droplet model of quantum spin glasses, particularly its prediction that the paramagnet-spin glass transition is unstable to even infinitesimal longitudinal fields. We then review the ongoing debate as to how well the droplet model describes 3D spin glasses and note that those inclined to view the intractability of NP-complete problems as a guiding physical intuition could take the results presented here as justifying greater suspicion toward the droplet model. Finally, due to this uncertainty as well as uncertainty in regard to the typical case classical complexity of this random NP-complete problem, we outline work using rigorous mean-field methods on a NP-complete problem whose typical-case classical complexity on random instances is better established, namely MAX CLIQUE on random graphs.

[1]This work is supported in part by ARDA and DoD under the AFOSR DURINT Program. WMK gratefully acknowledges fellowship support from the Fannie and John Hertz Foundation.

4:42PM W40.00012 Adiabatic Quantum Computing in systems with constant inter-qubit couplings , VADIM SMELYANSKIY, NASA Ames Research Center, SERGEI KNYSH, Mission Critical Technologies — We propose an approach suitable for solving NP-complete problems via adiabatic quantum computation with an architecture based on a lattice of interacting spins (qubits) driven by locally adjustable magnetic fields. Interactions between qubits are assumed constant and instance-independent, programming is done only by changing local magnetic fields. Implementations using qubits coupled by magnetic-dipole, electric-dipole and exchange interactions are discussed.

4:54PM W40.00013 Quantum Phase Transition and complexity of adiabatic quantum algorithm for Constraint Satisfaction problem , SERGEI KNYSH, Mission Critical Technologies, VADIM SMELYANSKIY, NASA Ames Research Center — We study the dynamics of adiabatic quantum computation (AQC) for solving the problem of satisfiability of randomly chosen clauses, each with 3 Boolean variables (3sat). We map this problem to that of a diluted long-range spin glass in traverse magnetic field and derive a self-consistent equation for the order parameter. We show the existence of the first-order quantum phase transition and investigate analytically and numerically the phase diagram on the plane: strength of the transverse field Γ vs the ratio γ=M/N of a number of clauses M to a number of variables N. We show that the phase transition line approaches Γ=0 at the point of a classical replica symmetry breaking transition γ_{RSB}. We discuss the implications of the quantum phase transition for the complexity of the AQC for the 3sat.

5:06PM W40.00014 Computation in Finitary Quantum Processes , KAROLINE WIESNER, University of California, Davis, JAMES P. CRUTCHFIELD, University of California, Davis — We introduce quantum finite-state generators as a first step toward a computational description of quantum dynamical processes. We developed their mathematical foundations, establishing probability conservation, reversibility, and consistency with quantum mechanical laws, and connect the class to the existing theory of finite-state recognizers and generators. These computational models allow for a quantitative description of quantum languages generated by quantum dynamical systems. Their descriptive power is explored via several example quantum dynamical systems.

5:18PM W40.00015 Some Thoughts Regarding Practical Quantum Computing , DEBABRATA GHOSHAL, RICHARD GOMEZ, George Mason University, MARCO LANZAGORTA, US Naval Research Laboratory, JEFFREY UHLMANN, University of Missouri - Columbia — Quantum computing has become an important area of research in computer science because of its potential to provide more efficient algorithmic solutions to certain problems than are possible with classical computing. The ability of performing parallel operations over an exponentially large computational space has proved to be the main advantage of the quantum computing model. In this regard, we are particularly interested in the potential applications of quantum computers to enhance real software systems of interest to the defense, industrial, scientific and financial communities. However, while much has been written in popular and scientific literature about the benefits of the quantum computational model, several of the problems associated to the practical implementation of real-life complex software systems in quantum computers are often ignored. In this presentation we will argue that practical quantum computation is not as straightforward as commonly advertised, even if the technological problems associated to the manufacturing and engineering of large-scale quantum registers were solved overnight. We will discuss some of the frequently overlooked difficulties that plague quantum computing in the areas of memories, I/O, addressing schemes, compilers, oracles, approximate information copying, logical debugging, error correction and fault-tolerant computing protocols.

Friday, March 17, 2006 8:00AM - 11:00AM –

Session Y40 TGQI DCMP: Solid State Quantum Computing I Baltimore Convention Center 343

8:00AM Y40.00001 Landau-Zener interferometry in a Cooper pair box , MIKA SILLANPÄÄ, TEIJO LEHTINEN, ANTTI PAILA, Low Temperature Laboratory, Helsinki University of Technology, Finland, YURIY MAKHLIN, The Landau Institute of Theoretical Physics, Moscow, Russia, PERTTI HAKONEN, Low Temperature Laboratory, Helsinki University of Technology, Finland — Quantum-mechanical systems having two crossing energy levels are ubiquitous in nature. The rate $v = d(E_1 - E_0)/dt$ at which such levels in a driven system approach each other determines the probability P_{LZ} of a Landau-Zener (LZ) tunneling between them. The traditional treatment of the LZ process, however, ignores quantum-mechanical interference. Here we report an observation of phase-sensitive interference between consecutive LZ tunneling attempts in an artificial two-state system, a superconducting charge qubit. We interpret the experiment in terms of a multi-pass analog to the optical Mach- Zehnder interferometer: The beam splitting occurs by LZ tunneling at the charge degeneracy, while the arms of the Mach- Zehnder interferometer in energy space are represented by the ground and excited state. In accord with theory, we observe constructive interference when the Stokes phase ϕ_S picked up during the LZ interaction, and the dynamical phase of one drive period $\phi = \int(E_1 - E_0)dt$ satisfy the condition: $(\phi - 2\phi_S) = m \cdot 2\pi$. Our LZ interferometer can be used as a high-resolution detector for phase and charge owing to interferometric sensitivity- enhancement.

8:12AM Y40.00002 Measuring the environmental impedance of the Cooper-pair box , BENJAMIN TUREK, JOHANNES MAJER, JOHN TEUFEL, Yale University, AASHISH CLERK, McGill University, STEVEN GIRVIN, ROBERT SCHOELKOPF, Yale University — The Cooper-pair box qubit measured by the SET can have long decoherence times that are limited by the quantum noise of the environment. Qubits fabricated at Yale are designed with 50 ohm transmission lines that control this environmental impedance to very high frequencies. We use the AC Josephson effect of a hysteretic DC-Squid to measure the frequency dependence of this impedance. At frequencies where the real part of the environmental impedance is large, the AC Josephson effect causes the small-junction analogue of self-induced Shapiro steps in the IV curves of a DC Squid [T. Holst et al., PRL 73, 3455 (1994)]. We determine that the environmental impedance of our qubit is well behaved at frequencies less than 20 GHz.

8:24AM Y40.00003 Anomalously low tunneling escape rates from the excited states of an inductively–isolated current–biased Josephson junction phase qubit[1] , R.M. LEWIS, T.A. PALOMAKI, HANHEE PAIK, S.K. DUTTA, A. PRZYBYSZ, B.K. COOPER, J.R. ANDERSON, A.J. DRAGT, C.J. LOBB, F.C. WELLSTOOD, University of Maryland — We present measurements of an inductively-isolated current-biased Nb/AlOx/Nb Josephson junction quantum bit at 20 mK. Density matrix fits of Rabi oscillations in our system suggest that the tunneling rate (Γ_1) from the first excited state is an order of magnitude lower than expected from a single current-biased junction. Furthermore, measurements of the energy relaxation time, T_1, through both pulse/decay and thermal population [2] techniques only agree if Γ_1 is approximately an order of magnitude lower than our single junction model predicts. To test for low Γ_1, we use a fast-ramp technique $(\alpha = d(ln\Gamma)/dt > 1/T_1)$ to directly measure Γ_1. We propose that an increase in the Josephson inductance of the qubit junction when in the excited state causes this effective reduction in Γ_1.

[1]Supported by NSF grant #EIA0323261, the NSA, and the Center for Superconductivity Research

[2]S. K. Dutta *et al.* , Phys. Rev. B **70** 140502(R) (2004).

8:36AM Y40.00004 Variable coupling between the inductively isolated current-biased Josephson junction qubit and the current bias leads[1] , HANHEE PAIK, S. K. DUTTA, R. M. LEWIS, R. C. RAMOS, H. XU, T. A. PALOMAKI, B. K. COOPER, A. J. PRZYBYSZ, A. J. DRAGT, J. R. ANDERSON, C. J. LOBB, F. C. WELLSTOOD, Center for superconductivity Research, Department of Physics, University of Maryland — We examined the behavior of inductively isolated Josephson junction qubits in which the coupling to the bias leads could be varied in situ. The variable coupling was achieved by using a second Josephson junction and an inductor that act as an inductive current divider. The coupling between the current bias leads and the qubit was varied by changing the current through the second junction, altering its Josephson inductance. We measured the tunneling escape rates of Al/AlO_x/Al and Nb/AlO_x/Nb junctions with continuous or pulsed microwave power, showing the allowed energy transitions and coherent Rabi oscillations. We found that T_2, T_2^* and T_1 did not change significantly as the coupling to the current bias leads was varied.

[1]This work is supported by NSA, NSF and Center for Superconductivity Research at University of Maryland. NSF grant number EIA0323261.

8:48AM Y40.00005 Analysis of Rabi Oscillations of a Josephson Phase Qubit[1] , S. K. DUTTA, H. XU, FREDERICK W. STRAUCH, PHILIP R. JOHNSON, R. C. RAMOS, HANHEE PAIK, T. A. PALOMAKI, R. M. LEWIS, J. R. ANDERSON, ALEX J. DRAGT, C. J. LOBB, F. C. WELLSTOOD, Department of Physics, University of Maryland — We have experimentally studied asymmetric Nb/AlOx/Nb dc SQUID qubits at 25 mK. The two lowest metastable levels localized within a single well of the complex two-dimensional potential of the device can serve as qubit states, if they are not unduly perturbed by resonant coupling to higher states of the full potential. Rabi oscillations between the qubit states can be driven with a microwave bias current. State readout is performed by measuring the tunneling rate from all energy levels with non-zero occupation probability to the finite voltage state. To interpret the results of our Rabi oscillation measurements, we have used a multi-level density matrix simulation to extract the populations of the individual quantum states from this total rate. We can then calculate the visibility of the oscillations and determine the effects of the higher levels and multi-photon transitions.

[1]This work is supported by the NSA, NSF Grant EIA 0323261, and the Center for Superconductivity Research.

9:00AM Y40.00006 Two Coupled Inductively-Isolated Josephson Junction Qubits[1] , TAUNO PALOMAKI, SUDEEP DUTTA, HANHEE PAIK, RUPERT LEWIS, ROBERTO RAMOS, HUIZHONG XU, BOB ANDERSON, CHRIS LOBB, FRED WELLSTOOD, University of Maryland — We report experimental measurements on coherent quantum oscillations and entangled macroscopic quantum states in two capacitively-coupled inductively-isolated $Nb/Al_2O_3/Nb$ Josephson qubits at 25mK. The interaction between the two qubits is controlled by tuning the energy level spacings of the junctions using the bias current and applied flux. We discuss transitions to various states of the coupled device, show Rabi oscillations, and analyze the spectroscopy of the system when the junctions are in and out of resonance with each other.

[1] This work is supported by the NSA, NSF Grant EIA 0323261, and the Center for Superconductivity Research.

9:12AM Y40.00007 Flux Noise in an Inductively Isolated Josephson Junction Qubit[1] , B. K. COOPER, HANHEE PAIK, R. M. LEWIS, S. K. DUTTA, T. A. PALOMAKI, A. J. PRZYBYSZ, J. R. ANDERSON, ALEX J. DRAGT, C. J. LOBB, F. C. WELLSTOOD, Department of Physics, University of Maryland — Martinis et al. [1] first proposed a technique for inductively isolating a Josephson junction qubit from the bias leads. It involves using one junction of a dc SQUID as a qubit, and the SQUID inductance and second junction of the SQUID as an inductance divider. This arrangement allows for isolation from current bias lines but potentially introduces greater sensitivity to flux noise. By introducing counterwound inductors on the qubit arm of the SQUID, we can reduce spatially uniform flux noise. We compare experimental coherence times for a $Nb/Al_2O_3/Nb$ qubit in such gradiometer designs to similar devices lacking the counterwound inductors. No significant difference is seen, suggesting that uniform flux noise is not the major source of decoherence in our system. [1] J. M. Martinis et al., PRL **89**, 117901

[1] This research is supported by NSF grant number EIA0323261, NSA and the Center for Superconductivity Research.

9:24AM Y40.00008 Measurement of Microwave Resonators for Improved T_1 in Josephson Qubits , MATTHEW NEELEY, M. ANSMANN, R. BIALCZAK, N. KATZ, E. LUCERO, R. MCDERMOTT, M. STEFFEN, E. WEIG, A. CLELAND, J. M. MARTINIS, UC Santa Barbara — To realize a quantum computer with Josephson qubits, the energy relaxation time T_1 must be increased by an order of magnitude or more over current qubits. One of the dominant sources of energy decoherence is dielectric loss due to two-level defect states in the Josephson junction and in wiring crossovers. Easily-fabricated microwave resonators provide a convenient way to measure the dielectric loss of candidate materials before incorporating them into qubits. We describe the measurement process and the results for several candidate dielectric materials. The loss tangents have been observed to vary with applied magnetic field. This variation is explained by a simple model of flux vortex trapping in the type I superconducting aluminum films of the resonators.

9:36AM Y40.00009 High Q Dielectrics for Josephson Phase Qubits , E. M. WEIG, M. ANSMANN, R. BIALCZAK, N. KATZ, E. LUCERO, R. MCDERMOTT, M. NEELEY, M. STEFFEN, J. M. MARTINIS, A. N. CLELAND, California NanoSystems Institute & Department of Physics, UC Santa Barbara — Dielectric loss in the bulk insulating material surrounding a superconducting phase qubit has recently attracted attention as a major source of decoherence. Dissipation arises from the excitation of a bath of two-level defects that is unsaturated in the limit of low microwave power and low temperature. This gives rise to much lower intrinsic Q factors than expected from material characterization typically performed in the saturated higher power or temperature regime. The density of these two-level systems in the insulator can be distinctively reduced by carefully choosing and engineering the dielectric material. We have investigated LC resonators fabricated using various amorphous dielectrics ranging from silicon dioxide or silicon nitride to silicon hydride (a-Si:H). The intrinsic Q factors of the materials have been measured at microwave frequencies in the unsaturated regime. The data demonstrates that by proper choice of material the dielectric loss tangent can be dramatically reduced, thus allowing for long coherence time phase qubits.

9:48AM Y40.00010 Fabrication and Testing of AlN Josephson Junction Qubits , RADOSLAW BIALCZAK, University of California, Santa Barbara, MARKUS ANSMANN, NADAV KATZ, ERIK LUCERO, ROBERT MCDERMOTT, MATTHEW NEELEY, MATTHIAS STEFFEN, EWA WEIG, ANDREW CLELAND, JOHN MARTINIS — Recently, it has been shown that a major source of decoherence in Josephson junction (JJ) qubits comes from coupling to two-level systems (TLS) in the dielectric materials used to construct these qubits. These TLS's result from defects in the dielectric material. In our previous work we have shown that the energy relaxation times of our JJ phase qubits improve 20-fold when we substitute SiO2 with SiN as the dielectric material used for cross-over wiring. This shows that nitride based dielectrics might be less prone to defects and suggests that the next logical step would be to replace the Al2O3 tunnel barrier dielectric of the JJ with AlN. We have used atomic nitrogen to successfully fabricate a JJ phase qubit with AlN as the JJ tunnel barrier material. Through spectroscopy measurements, we have found that qubits made with AlN as the tunnel barrier material have only slightly lower concentrations of defects compared with previously studied qubits made with Al2O3 grown by natural oxidation. Also, the measured T1 times for these AlN qubits were low (~15ns). This agrees with theoretical predictions of Ioffe et al. which state that piezoelectric materials, such as AlN, might have other loss mechanisms due to phonon radiation.

10:00AM Y40.00011 Evolution and decay of a superconducting Josephson junction qubit due to partial measurement , N. KATZ, M. ANSMANN, R. BIALCZEK, E. LUCERO, R. MCDERMOTT, M. NEELEY, M. STEFFEN, E. WEIG, A. CLELAND, J. M. MARTINIS, California NanoSystems Institute and Physics Dept., University of California, Santa Barbara, A. KOROTKOV, Electrical Engineering Dept., University of California, Riverside — Superconducting Josephson phase qubits have been shown to be a promising candidate for scalable quantum computing. In many such quantum computing algorithms, partial measurement of the quantum state is used to project the system into a required subspace. We experimentally study the effect of a partial measurement on our Josephson phase qubit using state tomography and high fidelity measurement capabilities. We also explore related multi-photon effects which appear naturally in such a system during state preparation, evolution and measurement.

10:12AM Y40.00012 Quantized Rabi oscillation observed in the superconducting flux qubit LC-harmonic oscillator system , K. SEMBA, J. JOHANSSON, S. SAITO, NTT Basic Research Labs, NTT Corp. and CREST Japan Science and Technology Agency, T. MENO, NTT Advanced Technology, H. NAKANO, NTT Basic Research Labs, NTT Corp. and CREST JSTA, M. UEDA, NTT Basic Research Labs, NTT Corp., CREST JSTA, Dept. of Physics, Tokyo Inst. of Tech., H. TAKAYANAGI, NTT Basic Research Labs, NTT Corp. and CREST JSTA — Superconducting circuit containing Josephson junctions is one of the promising candidates as a quantum bit (qubit) which is an essential building block for quantum computation. A flux qubit is represented by energetically lowest two collective states of macroscopic numbers of Cooper pairs which are linear combination of clockwise and counterclockwise persistent-current states. By replacing an atom with a flux qubit (artificial atom), and a high-Q cavity with an LC-circuit, quantum optics type experiments are possible on a superconductor chip. We have observed, for the first time, the vacuum Rabi oscillations in a superconducting flux qubit LC-oscillator coupled system [1]. We have also obtained evidence of level quantization of the LC circuit by observing the change in quantum oscillation frequency when the LC circuit was not initially in the vacuum state. Sharing a single superconducting LC-circuit with many flux qubits as a quantum information bus, spatially separated multiple qubits can be controlled by a set of microwave pulses. [1] J. Johansson et al., arXiv:cond-mat/0510457, http://www.brl.ntt.co.jp/group/shitsuryo-g/index.html

10:24AM Y40.00013 Quantum Computing Architectural Design , JACOB WEST, GEOFFREY SIMMS, MARK GYURE, HRL Laboratories, LLC. Malibu, CA — Large scale quantum computers will invariably require scalable architectures in addition to high fidelity gate operations. Quantum computing architectural design (QCAD) addresses the problems of actually implementing fault-tolerant algorithms given physical and architectural constraints beyond those of basic gate-level fidelity. Here we introduce a unified framework for QCAD that enables the scientist to study the impact of varying error correction schemes, architectural parameters including layout and scheduling, and physical operations native to a given architecture. Our software package, aptly named QCAD, provides compilation, manipulation/transformation, multi-paradigm simulation, and visualization tools. We demonstrate various features of the QCAD software package through several examples.

10:36AM Y40.00014 Threshold calculation and optimization for measurementless quantum error correction , GEOFFREY SIMMS, MARK GYURE, JACOB WEST, HRL Laboratories, LLC. Malibu, California — General-purpose quantum computing will rely on measurement as a primitive operation, but the operations of measurement and classical feed-forward are not necessary to perform certain useful computations, including quantum error correction. Measurementless quantum computation is appealing because it reduces the classical control system to an automaton, having no conditional operations. Measurementless, fault-tolerant quantum error correction (MFTQEC) of Calderbank-Shor-Steane (CSS) encoded logical qubits requires logical zero states to be prepared with high fidelity as an initial step, and this logical zero preparation has a threshold of its own, analogous to, but not identical to, the threshold of the entire error correction algorithm. In this talk, we present the results of mapping the MFTQEC algorithm onto a specific semiconductor-based qubit system using the Quantum Computing Architectural Design (QCAD) program, discussed in another talk in this session. The algorithm is translated from the set of "design gates" to the set of accessible "physical gates," and the resulting quantum circuit is optimized to improve the threshold. Limited 2-dimensional connectivity is assumed, making this well suited to the "enhancement mode" quantum dot qubits described in other talks in this session.

10:48AM Y40.00015 Shift register in a SQUID architecture with untunable couplings[1] , PREETHIKA GAGNEBIN, STEVEN SKINNER, Department of Electrical and Computer Engineering, Wichita State University, ELIZABETH BEHRMAN, Department of Physics, Wichita State University, JAMES STECK, Department of Aerospace Engineering, Wichita State University — A scheme to implement a qubit shift register in a one-dimensional series of superconducting quantum interference devices (SQUIDs), using a sequence of pulsed biases, is described. Each SQUID is coupled to its neighbors through an untunable coupling parameter. The only variable parameter of the system is the bias on each SQUID, which is pulsed low during a shift operation. Our design requires only two bias control signals for any size of shift register, with an additional one on the output qubit to shift out the data. The shift register operation is realized by copying the state of one qubit onto another, in the direction of the shift, during the bias pulse. As the no-cloning theorem prohibits the cloning of an unknown arbitrary quantum state, this device works as a classical shift register or, in other words, a binary wire. We show here how to find the time duration of the bias pulse and the minimum value of the bias during the pulse given the fixed physical parameters of the system.

[1]Supported by NSF, ECS 0201995

Friday, March 17, 2006 11:15AM - 2:03PM –
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11:15AM Z40.00001 Double quantum dot coupled to a superconducting single-electron transistor for measurement of back action , MADHU THALAKULAM, Rice University, Houston, TX 77005, JOEL STETTENHEIM, A. J. RIMBERG, Dartmouth College, Hanover, NH 03755, L.N. PFEIFFER, K. W. WEST, Bell Laboratories, Lucent Technologies Inc., Murray Hill, NJ 079745 — The superconducting single electron transistor SET is a highly sensitive electrometer operating near the quantum limit. The back action current noise of the SET has been a topic of interest ever since the SET was proposed as a readout device for charge or spin based qubits [1]. We study the back-action noise of a superconducting SET by means of an electrostatically coupled double quantum dot (DQD) system. Inelastic current through the DQD is sensitive to the spectral density of voltage fluctuation in its electromagnetic environment [2,3]. By properly choosing the dot size and inter-dot tunnel barrier, one can cause inelastic processes to dominate the transport. A measurement of the inelastic current through the double dot system can then be used to calculate the spectral density of quantum noise associated with the RF-SET and hence its back-action. We have fabricated samples consisting of a DQD formed in a GaAs/AlGaAs heterostructure and strongly coupled to an Al/AlO_x/Al SET. Recent results of measurements on such devices will be discussed. [1] M.H. Devoret and R.J. Schoelkopf, Nature, **406**, 1039(2000). [2]T. Fujisawa et al., Science, **282**, 932 (1998). [3]R. Aguado and L. P. Kouwenhoven, Phys. Rev. Lett., **84**, 1986(2000).

11:27AM Z40.00002 Quantum Capacitance for Quantum Computation , C.M. WILSON, T. DUTY, F. PERSSON, M. SANDBERG, G. JOHANSSON, L. TORNBERG, J. BYLANDER, P. DELSING, Chalmers University — We present measurements of superconducting quantum bit (qubit) circuits utilizing the quantum capacitance (QC) of a single cooper-pair box (SCB). The QC is essentially the curvature of the SCB energy bands near the charge degeneracy point, and has recently been measured by our group and others. The curvature arises from the avoided level crossing induced by the Josephson coupling of the SCB. The QC can be much larger than the geometric capacitance, and changes sign between the ground and excited states. We present a qubit with integrated readout that embeds a SCB in a resonant circuit and detects changes in the QC as changes in the phase of a reflected microwave signal. We have calculated that this readout method is strictly quantum limited independent of the quality factor (Q) of the the resonator. This allows great flexibility in the design and optimization of the readout. Calculations show that the method should be able to achieve single-shot discrimination of the qubit state under realistic experimental conditions. We also present preliminary measurements of coupled qubit circuits, with both fixed coupling and a variable coupling scheme based on the ground-state QC.

11:39AM Z40.00003 Manipulation and readout of deep-submicron Nb-trilayer-based persistent-current qubits[1] , DAVID M. BERNS, SERGIO O. VALENZUELA, MIT, WILLIAM D. OLIVER, MIT Lincoln Laboratory, TERRY P. ORLANDO, MIT — Lithographically patterned persistent-current (PC) qubits are promising candidates for realizing a large-scale quantum computer. While challenging to fabricate in a trilayer technology, deep-submicron Josephson junctions (JJs) are required to realize large qubit tunnel-couplings and allow improved immunity to dielectric-induced decoherence. Here, we present recent results on the measurement and characterization of PC qubits designed with deep-submicron JJs and fabricated with Nb-Al/AlOx-Nb trilayers.

[1]This work is supported in part by the AFOSR grant F49620-01-1-0457 under the DoD University Research Initiative on Nanotechnology (DURINT) Program and the AFOSR/NM grant FA 9550-04-1-0221.

11:51AM Z40.00004 Macroscopic Quantum Coherence in a Multi-Level Nb Persistent-Current Qubit[1]

, YANG YU, MIT, W. D. OLIVER, MIT Lincoln Laboratory, J. C. LEE, K.K. BERGGREN, L.S. LEVITOV, T.P. ORLANDO, MIT — We drove a niobium persistent-current qubit with strong microwaves and observed single-, two-, and three-photon transitions between its macroscopic quantum states. A multi- level energy-band diagram was extracted by mapping the frequency of the induced transitions as a function of applied magnetic flux to the qubit, and the anti-crossing caused by the superposition between the third and fourth excited states were directly measured. The energy relaxation time T1 between two states connected by multi-photon transitions ranged from 30 to 100 ms. In addition, three-photon coherent temporal oscillations between the ground state and fourth excited state were observed with a decoherence time of approximately 50 ns.

[1]Supported by AFOSR Grant No. F49620-01-1-0457 and the DOD under the Air Force, Contract No. F19628-00-C-0002

12:03PM Z40.00005 Electronic control and readout of qubit states in Si:Li-based quantum computing system

, V.V. OSIPOV, V.N. SMELYANSKIY, NASA Ames Research Center, Moffett Field, CA, A.G. PETUKHOV, Physics Department, South Dakota School of Mines and Technology — In our previous work (V. N. Smelyanskiy *et al.* Phys. Rev. B **72**, 081304 (2005)) we predicted a gigantically long lifetime of the first excited state of an interstitial lithium donor in silicon. The nature of this effect roots in the anomalous level structure of the $1s$ Li manifold under external stress. Namely, the coupling between the lowest two states of the opposite parity is very weak and occurs via intervalley phonon transitions only. We proposed to use these states under the controlled ac and dc stress to process quantum information. In this work we consider some practical aspects of the proposed scheme such as formation of heavily doped semiconductor electrodes for electrical control of the qubit states and single-qubit readout by means of the resonant tunneling stimulated by polarized infrared radiation. We propose a proof-of-the principle experiment on photo-stimulated time-dependent resonant tunneling in a δ-doped layer of Li donors in Si placed between two n^+ Si electrodes. The effect will be characterized by a high sensitivity of the signal to the polarization of photons and by long-term relaxation of the resonant tunneling photocurrent.

12:15PM Z40.00006 Single electron tunneling in a controllable electromagnetic environment

, Z. JI, Rice University, W. XUE, A.J. RIMBERG, Dartmouth College, L.N. PFEIFFER, K.W. WEST, Bell Laboratories — Real-time counting of single electrons is the most fundamental means of measuring current [1]. Direct observation of single electron tunneling oscillations requires embedding a tunnel barrier in a high-impedance electromagnetic environment. Beginning with a two dimensional electron gas in a GaAs heterostructure we first etch a narrow mesa to serve as a conducting channel. We fabricate two staggered arrays of quantum point contacts (QPCs) across the mesa to serve as ballistic resistors controlled by tuning the QPC gate voltage. An additional QPC placed between the arrays serves as the tunnel barrier and a nearby radio-frequency single electron transistor (RF-SET) serves as an electrometer. We have fabricated several such samples. Typically the conductance G versus gate voltage of such an array of 10 QPCs shows plateau-like structures at fractions of the conductance quantum, $G_0 = 2e^2/h$. The first plateau, below which the conductance drops rapidly to zero, is the preferred working point corresponding to one open channel in each QPC. When the arrays are at their working points and the central barrier is formed, the samples show a large gap in their I-V characteristics corresponding to dynamical Coulomb blockade. Recent measurements of such samples will be presented, and the use of the RF-SET to directly observe single electron tunneling will be discussed. [1] J. Bylander, T. Duty and P. Delsing, Nature **434**, 361 (2005).

12:27PM Z40.00007 Calculated tunneling rates for single electron charging events in Vertical "Enhancement Mode" quantum dot devices.

, RICHARD ROSS, MARK GYURE, HRL Laboratories, LLC, CHRIS ANDERSON, Dep't of Mathematics, UCLA — We report on calculations of tunneling rates associated with single electron charging events in vertical "enhancement mode" quantum dot device structures. These devices consist of two vertically stacked quantum well layers. A pair of surface depletion gates define a Quantum Point Contact (QPC) and a single localized enhancement gate creates a quantum dot (QD) in the upper quantum well. Single electron charging events in this device occur via tunneling between the vertically separated QD and QPC states. Tunneling rates are computed using Fermi's Golden Rule based on numerical eigenstates derived from fully 3-dimensional self-consistent Poisson-Schroedinger calculations. The effects of coulomb interaction on the quantum dot states and hence tunneling rates will be considered. Additionally, a comparison of these numerical results with experimental estimates of tunneling rates derived from random telegraph signals will be presented.

12:39PM Z40.00008 Observation of Sequential Single Electron Charging in Vertical "Enhancement Mode" Quantum Dot Devices[1]

, EDWARD CROKE, GEOFFREY SIMMS, MARK GYURE, HRL Laboratories, LLC — The vast majority of devices currently being explored for quantum information processing with semiconductor quantum dots rely on multiple surface gates operating in reverse bias (depletion mode) to constrict a buried 2D electron gas to the few electron regime. Although successful in demonstrating one and two qubit operations, they are unlikely to scale to large arrays that are needed to perform practical quantum information processing. In this talk, we present the first experimental results from a new type of "enhancement mode" device that requires only a single gate electrode operating in forward bias to create a few electron quantum dot. We observe random telegraph signals in several well defined regions of gate voltage, indicative of single electrons tunneling between states of the quantum dot and the readout channel. The absence of these signatures below a particular gate voltage suggests that these quantum dots are in the few electron regime and can be easily depleted to contain only one electron.

[1]This work was supported by the Defense Advanced Research Projects Agency and the Army Research Office under Contract Number DAAD19-01-C-0077.

12:51PM Z40.00009 Analysis of Random Telegraph Signals from Vertical "Enhancement Mode" Qunatum Dot Devices

, MARK GYURE, GEOFFREY SIMMS, RICHARD ROSS, EDWARD CROKE, HRL Laboratories, LLC — Clear signatures of single electron tunneling in vertical "enhancement mode" semiconductor quantum dot devices have recently been observed. These devices hold great promise for future scalability of semiconductor-based quantum information processing because they require only a single gate electrode to create the quantum dot. In this talk, we present a detailed analysis of the random telegraph signals observed in these devices as various N to N+1 electron transitions are swept through by varying the gate voltage and magnetic field. This analysis allows us to extract a variety of information about the transitions and further supports our conclusion that electrons are tunneling between the gate-induced quantum dot and the readout channel below. Results of self-consistent Schrodinger-Poisson simulations of these devices are presented that also support this interpretation of the experimental results.

1:03PM Z40.00010 MOSFET-like single electron transistor built in pure silicon

, G.M. JONES, B.H. HU, C.H. YANG, Department of Electrical and Computer Engineering, University of Maryland at College Park, M.J. YANG, Naval Research Laboratory — Solid state implementations of qubits offer the advantage of being scalable, and, in particular, those based on semiconductors can be integrated by existing technologies. The two Zeeman states of an electron spin in a quantum dot (QD) provide a promising candidate for a qubit, and lateral quantum dots provide the best opportunity for scaling. Spins in lateral QDs in the GaAs/AlGaAs single electron transistors (SETs) have been intensively investigated. In contrast, Si provides a number of advantages, including long spin coherence time, large g-factor, and small spin-orbit coupling effect. However, isolation of a single electron in a Si QD has not yet been achieved. We will report a fabrication technique that utilizes the established MOSFET concept on highly resistive Si substrates in order to minimize the potential disorder resulting from impurities. In our approach, 2D (or 1D) electrons are induced by a top gate, which laterally overlaps with the ion-implanted source/drain, but vertically separated by SiO2. Several side gates buried in the SiO2 help define the tunneling barriers and control the number of electrons in the island. We will discuss the operating principle, computer simulation, and experimental results that confirm the validity of the design concept.

1:15PM Z40.00011 Proposal to stabilize and detect half-quantum vortices in strontium ruthenate thin films: Non-Abelian braiding statistics of vortex matter in a $p_x + ip_y$ superconductor[1] ,

SUMANTA TEWARI, SANKAR DAS SARMA, Condensed Matter Theory Center, Department of Physics, University of Maryland, College Park, MD 20742, CHETAN NAYAK, Microsoft Research, Project Q, Kohn Hall, University of California, Santa Barbara, CA 93108 — We propose a simple way to stabilize half-quantum vortices in superconducting strontium ruthenate, assuming the order parameter is of chiral $p_x + ip_y$ symmetry, as is suggested by recent experiments. The method, first given by Salomaa and Volovik in the context of Helium-3, is very naturally suited for strontium ruthenate, which has a layered, quasi-two-dimensional, perovskite crystal structure. We propose possible experiments to detect their non-abelian braiding statistics. These experiments are of potential importance for topological quantum computation.

[1]Work supported by the ARO-ARDA

1:27PM Z40.00012 Measurement errors for phase qubits[1] ,

QIN ZHANG, ABRAHAM KOFMAN, ALEXANDER KOROTKOV, University of California, Riverside — We analyze error mechanisms in measurement of superconducting phase qubits, including measurement cross-talk for two coupled phase qubits and effect of nonadiabaticity during the measurement pulse. Each qubit is represented by a fictitious particle moving in an asymmetric double-well potential. A measurement, e.g., of the state $|10\rangle$ perturbs the second qubit which may result in a wrong measurement result $|11\rangle$. In the study of this cross-talk the first qubit is described classically, since it is highly excited, whereas the second qubit can be treated either classically or quantum- mechanically. We obtain conditions for minimizing the cross- talk. We also study the nonadiabatic errors for different shapes and durations of the measurement pulse and discuss optimal conditions for fast and reliable measurements.

[1]Supported by NSA/ARDA/ARO grant

1:39PM Z40.00013 Entanglement distillation by adiabatic passage in coupled quantum dots[1] ,

JAROSLAV FABIAN, University of Regensburg, ULRICH HOHENESTER, University of Graz — Adiabatic passage of two correlated electrons in three coupled quantum dots is shown to provide a robust and controlled way of distilling, transporting and detecting spin entanglement, as well as of measuring the rate of spin disentanglement. Employing tunable interdot coupling the scheme creates, from an unentangled two-electron state, a superposition of spatially separated singlet and triplet states. A single measurement of a dot population (charge) collapses the wave function to either of these states, realizing entanglement to charge conversion. The scheme is robust, with the efficiency close to 100%, for a large range of realistic spectral parameters.

[1]Work supported by US ONR

1:51PM Z40.00014 Detecting the squeezing and entanglement of nanomechanical modes: a practical scheme ,

L. TIAN, S. M. CARR, National Institute of Standards and Technology, 100 Bureau Drive, Stop 8423, Gaithersburg, MD 20899 — Nanomechanical systems are promising candidates for realizing the continuous variable protocols of quantum information processing. The detection of the squeezing and entanglement of nanomechanical modes is a crucial step towards such applications. Here, we show that by coupling a nanomechanical mode with another continuous variable mode – a superconducting phase variable, the squeezing and entanglement can be observed within current experimental techniques.