Q 6: Quanteninformation (Atome und Ionen II)

Zeit: Montag 16:30–19:00 Raum: 1B

Q 6.1 Mo 16:30 1B

A table-top experiment on the early universe — •Hector Schmitz, Axel Friedenauer, Jan Glückert, Lutz Petersen, Steffen Kahra, Günter Leschhorn, Christian Schneider, Robert Matjesch, and Tobias Schätz — MPQ Garching

Having a look at the conditions of the early universe isn't easy. Even state of the art accellerators are not able to create the extremely high energies gouverning the very first cosmological period in which quantum phenomena become crucial in the development of space and time.

Some details might be accessible for investigations in an analog way, namely the creation of new particle-antiparticle pairs within the violent days of the inflationary epoch of the universe. Following calculations [1,2] an analog vaccuum quantum processes that might have lead to the creation of new pairs of photons and other particles during a phase of rapid expansion should create pairs of phonons in an ion crystal if the confining potential is changed exponentially.

Here we present and discuss the realisation of this simulation in a linear Paul trap. A single ion is cooled via sideband cooling down to the motional ground state – mimicing the ground state of the vaccuum. Then the confining potential is lowered slowly. While the potential raises nonadiabatically back to its initial strength, pairs of phonons will show up, whose signature is discriminated form heating processes.

[1] R. Schützhold, T. Schätz et. al., Phys. Rev. Lett. 99, 201301 (2007)
[2] "Quantum quirk may reveal early universe", New Scientist 2607, p. 11 (2007)

Q 6.2 Mo 16:45 1B

Experimental techniques for quantum information processing with trapped ^{43}Ca^{+} ions — •Gerhard Kirchmair^{1,2}, Jan Benhelm^{1,2}, René Gerritsma^{1,2}, Florian Zähringer^{1,2}, Christian Roos^{1,2}, and Rainer Blatt^{1,2} — ^{1}Institut für Experimentalphysik, Universität Innsbruck, Österreich — ^{2}Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Innsbruck, Österreich

We demonstrate the complete set of experimental techniques that are necessary to employ the isotope ^{43}Ca^{+} for quantum information processing. Ground state cooling, robust state initialization and efficient read out are experimentally realized on a single ^{43}Ca^{+} ion. With microwave transitions, we find the coherence time for storing quantum information in the hyperfine qubit ($F = 4, m_F = 0 \leftrightarrow F = 3, m_F = 0$) to be many seconds. Phase coherence during the interaction with a Raman laser is sustained for more than 200 ms. All techniques are also applicable to ion strings and the ability to move the ions makes individual addressing possible. We show that the motional coherence of a single ion is preserved during the shuttling process.

Q 6.3 Mo 17:00 1B

Realization of decoherence-free ion trap quantum computation — •Kihwan Kim^{1}, Thomas Monz^{1}, Alessandro Villar^{2}, Philipp Schindler^{1}, Michael Chwalla^{1}, Mark Riebe^{1}, Markus Hennrich^{1}, Wolfgang Hänsel^{1}, and Rainer Blatt^{1,2} — ^{1}Institut für Experimentalphysik, Universität Innsbruck, Austria — ^{2}Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Austria

Quantum computation is limited by decoherence from technical noise and coupling of the qubits to the environment. However, certain states were shown to be protected from decoherence due to their symmetry [1]. These states form a decoherence-free subspace (DFS) of the Hilbert space. Using the DFS as a robust computational space will help to realize large scale quantum computing. In this talk we show the first realization of a universal set of gate operations in a DFS with ion strings. We use trapped ^{40}Ca ions and store quantum information in the ion's electronic states $S_{1/2}$ and $D_{5/2}$. A DFS is formed by the two states $|SD\rangle$ and $|DS\rangle$ which are used as logical qubits $|0_L\rangle$ and $|1_L\rangle$. In this DFS, single-qubit rotations are realized using a Mølmer-Sørensen gate between the two ions of the logical qubit. For two-qubit operations between logical qubits a σ_z-type geometric phase gate is applied to neighbouring ions of two adjacent logical qubits [2]. We obtain fidelities of around 94% for a single qubit $\pi/2$-rotation and around 75% for a CNOT gate in DFS.

[1] D. Kielpinski et al., Nature 417, 709 (2002).
[2] L. Aolita et al., Phys. Rev. A 75, 052337 (2007).

Q 6.4 Mo 17:15 1B

Optimised particle transport in a potential well — •Michael Murphy and Tommaso Calarco — Inst. f. Quanteninformationsverarbeitung, Ulm, D

We analyse a quantum system with which we require non-adiabatic transport of a specified quantum state. We first consider analytically the situation of a 1-d harmonic potential confining a particle in a given quantum state, corresponding to the motional states of bound particles such as ions in a microtrap, or atoms in an optical lattice. We show analytic solutions exist for the transport function such that perfect transport is achieved in an arbitrary time, by which we mean that given an initial quantum state, the final state is the same as the initial state but displaced by our transport distance, and the state has evolved only as one would have found in a static harmonic potential. We also show that the system is robust against a class of distorting functions that describe homogeneous broadening. Furthermore, we apply Optimal Control Theory to optimise the transport function when the system is coupled to the environment.

Q 6.5 Mo 17:30 1B

Nichtadiabatischer Transport von Ionen in einer segmentierten, linearen Paulfalle in Leiterplattentechnologie — •Gerhard Huber, Thomas Deuschle, Wolfgang Schnitzler, Max Hettrich, Rainer Reichle, Kilian Singer und Ferdinand Schmidt-Kaler — Universität Ulm, Institut für Quanteninformationsverarbeitung, Albert-Einstein-Allee 11, 89069 Ulm

Wir beschreiben die Konstruktion und den Betrieb einer segmentierten, linearen Paulfalle, gefertigt in Leiterplattentechnologie mit einer Segmentbreite von 500 μm [1]. Um die Eignung dieser Technologie zum Fangen und Manipulieren geladener Teilchen zu demonstrieren, speichern und laserkühlen wir Kristalle aus einzelnen ^{40}Ca^{+}-Ionen. Die gemessenen radialen und axialen Fallenfrequenzen stimmen bis auf wenige Prozent mit den durch numerische Rechnungen vorhergesagten Werten überein.

Um die Vielseitigkeit und Verlässligkeit dieser Fallentechonologie zu demonstrieren, untersuchen wir den Transport einzelner Ionen entlang der Fallenachse über eine Distanz von 2 mm hin und zurück. Die durchgeführten Experimente ergeben hohe Erfolgsraten auch im Bereich sehr schneller, nichtadiabatischer Transporte, die nur noch wenige axiale Oszillationsperioden des Ions dauern. Wir untersuchen in numerischen Simulationen und experimentell die durch solche schnellen Transporte erzeugte Vibrationsanregung des Ions.

[1] G. Huber et al., arXiv:0711.2947v1

Q 6.6 Mo 17:45 1B

Efficient coupling of light to a single molecule and the observation of its fluorescence Mollow triplet — •Martin Pototschnig, Gert Wrigge, Ilja Gerhardt, Jaesuk Hwang, Lutz Petersen, and Vahid Sandoghdar — Laboratory for Physical Chemistry, ETH Zurich, CH-8093 Zurich, Switzerland

Dye molecules in organic matrices are solid-state quantum emitters that can have lifetime limited linewidths at temperatures below 2K. Single molecules in such systems have been conventionally detected with fluorescence excitation spectroscopy, where the molecule is excited via its narrow zero-phonon line and its Stokes-shifted emission is detected. We report here on the coherent detection of a single molecule in transmission. Our experiments in the near- [1,2] and far-field [3] directly show between 5 and 12% dip on the transmission of a laser beam without using any noise suppression methods such as lock-in detection. Our efficient coupling of light to a single molecule has allowed us to study its resonance fluorescence over 9 orders of magnitude. We will show the power dependent coherent scattering and the first direct measurement of the Mollow fluorescence triplet in a solid-state system [3]. In the weak excitation regime we show that it is possible to detect a single molecule by using excitation powers below a femtoWatt. The efficient coupling combined with the coherent nature of extinction detection pave the way for further fundamental quantum optical experiments. [1]I.Gerhardt et. al., PRL 98,033601(2007). [2]I.Gerhardt et. al., OL 32,1420(2007). [3]G.Wrigge et. al., arXiv:0707.3398 to appear in Nature Physics.

Q 6.7 Mo 18:00 1B

Erzeugung zweidimensionaler Cluster-Zustände mit gespeicherten Ionen — •Harald Wunderlich und Christof Wunderlich — Fachbereich Physik, Universität Siegen, 57068

Cluster-Zustände bilden die Grundlage für den sogenannten *One-Way Quantum Computer* [1]. Die zu Grunde liegenden Cluster können in unterschiedlichen Dimensionen existieren. Zur Realisierung eines universellen Satzes von effizienten Quanten-Gattern mit dem One-Way Quantum Computer werden mindestens zwei Dimensionen benötigt. Wir zeigen, dass die Erzeugung von zweidimensionalen Cluster-Zuständen mit Ionen, welche in einem linearen elektrodynamischen Käfig gespeichert werden, effizient möglich ist, wenn diese über eine, durch ein zusätzliches Magnetfeld induzierte Spin-Spin-Wechselwirkung gekoppelt sind [2] . Ein beliebiger zweidimensionaler $n \times m$-Cluster kann durch einen $n \times 2$-Cluster simuliert werden. Es wird ein Verfahren entwickelt, um solche $n \times 2$-Cluster zu generieren, welches lediglich auf einem linearen Cluster-Zustand und Selective-Recoupling-Sequenzen mit vier Ionen beruht. Der experimentelle Aufwand zur Realisierung eines zweidimensionalen Clusters wächst nach diesem Schema lediglich linear mit der Anzahl der Ionen.

[1] R. Raussendorf, H. J. Briegel, Phys. Rev. Lett. **86**, 5188-5191 (2001).

[2] Chr. Wunderlich, in *Laser Physics at the Limit* (Springer, Heidelberg, 2002), p. 261; auch quant-ph/0111158.

Q 6.8 Mo 18:15 1B

A quantum memory of light in nuclear spins of a quantum dot — •Heike Schwager, Geza Giedke, and Ignacio Cirac — Max-Planck Institut für Quantenoptik, 85748 Garching

A quantum memory is an essential building block for quantum information and communication. Nuclear spins have long decoherence times and are thus a good candidate for a quantum memory.

We couple the field of an optical microcavity to the polarized nuclear spins of a charged quantum dot by a detuned Raman process. Eliminating the trion, we show that STIRAP allows to map the state of the cavity field to the nuclei. Similar techniques can be used to generate two-mode squeezed states of the nuclear spin-cavity system, enabling e.g. a light matter interface through teleportation.

Q 6.9 Mo 18:30 1B

Gauss sum factorization with cold atoms — •Michael Gilowski, Thijs Wendrich, Christian Schubert, Ernst M. Rasel, and Wolfgang Ertmer — Institut für Quantenoptik, Leibniz Universität Hannover

A factorization scheme taking advantage of the periodicity properties of Gauss sums has been proposed [1] and recently verified by two NMR-experiments [2] and one experiment based on short laser pulses [3]. In the present contribution we report the first implementation of a Gauss sum factorization based on matter-wave interferometry with cold rubidium atoms [4].

The implementation of the Gauss sums is performed by applying a sequence of light pulses which imprints on a two-level quantum system a sequence of well-defined phases. For appropriately chosen pulses the excitation probability takes the form of a Gauss sum. With this technique we factor the number N=263193. In contrast to the Shor algorithm our method in the present form is based on classical atomic ensembles and does not take benefit of the parallel computing of quantum information. The experimental realization as well as the results of the factorization experiment will be presented. This work is supported by SFB 407 and the FINAQS cooperation of the European Union.

[1] Clauser, et al. Phys. Rev. A **53**, 4587 (1996) and Harter, et al. Phys. Rev. A **64**, 012312 (2001) [2] Mehring, et al. Phys. Rev. Lett. **98**, 120502 (2007) and Mahesh, et al. Phys. Rev. A **75**, 062303 (2007). [3] Bigourd, et al. Phys. Rev. Lett. in press. [4] Gilowski, et al. Phys. Rev. Lett. in press.

Q 6.10 Mo 18:45 1B

Efficiency of entanglement of distant atoms by projective measurement — Georgina Olivares Renteria[1], Stefano Zippilli[1], Giovanna Morigi[1], Felix Rohde[2], •Carsten Schuck[2], and Jürgen Eschner[2] — [1]Departament de Fisica, Universitat Autonoma de Barcelona, 08193 Bellaterra, Spain — [2]ICFO - Institut de CIencies Fotoniques, 08860 Castelldefels (Barcelona), Spain

We compare the efficiency of two schemes for the preparation of entangled states of distant atoms proposed in [1,2]. In these proposals the atoms do not interact and the entanglement is realized by means of the measurement of the scattered field which project the two atoms into the desired state. We quantify the efficiency of the schemes using the fidelity between the state of the system after the detection of a photon and an ideal entangled state of the two atoms. In [1] the atoms interact with two optical cavities and the enhanced probability of emission into the cavities allows for high detection efficiency. This scheme is limited by the finite probability of emission of two photons. Thus, even under the assumption of perfect detection efficiency, the fidelity of the scheme never reaches unity. In [2] emission of two photons is suppressed by low excitation strength, but the detection efficiency is low since the atoms scatter into free space and only a small fraction of the photons is measured. In this case the fidelity is conditioned on single-photon detection and results to be higher. The comparison is quantitatively evaluated for an ongoing experiment with two distant trapped single Ca+ ions. [1] S. Bose, et al, Phys. Rev. Lett. 83, 5158 (1999). [2] C. Cabrillo, et al, Phys. Rev. A 59, 1025 (1999).