The conference is organized by Center for Theoretical Physics of the Polish Academy of Sciences, Institute of Physics of the Polish Academy of Sciences and Faculty of Physics of Warsaw University.

This is the sixth conference of the cycle, the previous one was held in Kościelisko, Poland in 2001. This time the main subject of the conference is Quantum Engineering of Atoms and Photons. The meeting is focused on the physics of ultracold quantum gases, which without doubts determines the frontiers of the modern atomic, molecular and optical physics. Special attention is also given to quantum information processing, both from theoretical and experimental point of view, including possible realizations in ultracold quantum gases.

The conference consists of invited lectures and a poster session.

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We wish to thank the following for their contribution to the success of this conference: European Science Foundation, Committee on Physics of the Polish Academy of Sciences, European Office of Aerospace Research and Development of the USAF and the U.S. Army International Technology Center-Atlantic, European Research Office.

The beauty of the Riemann–Silberstein vector

Iwo Białynicki-Birula

Center for Theoretical Physics, Warsaw, Poland

Beams of light carrying angular momentum have recently been widely studied theoretically and experimentally. In my talk I will show that the description of these beams in terms of the Riemann–Silberstein vector offers many advantages. In particular, it provides a natural bridge between the classical and the quantum description.

Spatial quantum state tomography for photons

M.G. Raymer, B.J. Smith, Bryan Killett, Andrew Nahlik

Oregon Center for Optics and Department of Physics,
University of Oregon, Eugene, Oregon, USA

K. Banaszek, I.A. Walmsley

Clarendon Laboratory, University of Oxford, Oxford, UK

We present a method to measure the transverse spatial quantum state of an optical field in coordinate space at the single-photon level. A photon is an elementary excitation of the electromagnetic field. If it is known that only one such excitation exists, it can be treated as a (quasi-) particle, roughly analogous to an electron. Because a photon is a spin-one particle, its wave function should have three components, forming a (non-operator) vector field $\underline{\psi}(\underline{r})$. Białynicki [1] and Sipe [2] have argued convincingly that the complex, classical Maxwell field plays such a role. The complex Maxwell field is $\underline{\psi}(\underline{r}) = \underline{E}(\underline{r}) + \mathrm{i}\underline{B}(\underline{r})$, where $\underline{E}(\underline{r})$ and $\underline{B}(\underline{r})$ are the usual transverse electric and magnetic fields. The function $\underline{\psi}(\underline{r})$ obeys the transversality condition $\underline{\nabla} \cdot \underline{\psi}(\underline{r}) = 0$, and the wave equation

$$\mathrm{i}\frac{\partial}{\partial t}\underline{\psi}(\underline{r}) = c\underline{\nabla} \times \underline{\psi}(\underline{r}). \tag{1}$$

If this equation is (second) quantized, it becomes the standard (Dirac) electromagnetic theory of quantum optics [3]. A single-photon state of the quantized field can be represented by $|\Psi\rangle = \int \mathrm{d}^3k C(\mathbf{k})\hat{b}^\dagger(\mathbf{k})|\mathrm{vac}\rangle$, where $\hat{b}^\dagger(\mathbf{k})$ creates a one-photon state with definite momentum $\mathbf{p} = \hbar\mathbf{k}$. The function $\underline{E}^{(+)}(\underline{r}, 0, t) = \langle\mathrm{vac}|\underline{\hat{E}}^{(+)}(\underline{x}, 0, t)|\Psi\rangle$ obeys the Maxwell equation and contains all of the state information, and can be viewed as the quantum wave function of the single photon.

If we know the photon's frequency, but not its mode function (transverse spatial state), we can perform ensemble measurements

that will tell us the spatial state. The Wigner function of a state equals the expectation value of the parity operator $\hat{\Pi}$, evaluated with the state's density operator $\hat{\rho}(x, k_x)$ that has been displaced a distance x and tilted by an angle $\theta = \arcsin(k_x/k_0)$,

$$W(x, k_x) = 2\,\mathrm{Tr}\left[\hat{\rho}\hat{D}(x, k_x)\hat{\Pi}\hat{D}^{-1}(x, k_x)\right] = 2\,\mathrm{Tr}\left[\hat{\rho}(x, k_x)\hat{\Pi}\right], \tag{2}$$

where $\hat{D}(x, k_x)$ is the phase-space displacement operator. This means we can measure the Wigner function directly using a parity-inverting, photon-counting Sagnac interferometer [4].

The measurements are made with a photon-counting Sagnac interferometer based on all-reflecting optics. The technique provides a large numerical aperture without distorting the shape of the wave front, does not introduce astigmatism, and allows for characterization of fully or partially coherent optical fields at the single-photon level [5]. Measurements of the transverse spatial Wigner functions for highly attenuated coherent beams are presented and compared to theoretical predictions. The ability to measure quantum states or wave functions for ensembles of single photons can be generalized to pairs of photons [4].

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Quantum state reconstruction via continuous measurement

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A new procedure for quantum state reconstruction is presented, based on weak continuous measurement of an ensemble average. By applying controlled evolution to the initial state, new information is continually mapped onto the measured observable. A Bayesian filter is then used to update the state-estimate in accordance with the measurement record. This generalizes the standard paradigm for quantum tomography based on strong,

destructive measurements on separate ensembles. This approach to state estimation induces minimal perturbation of the measured system, giving information about observables whose evolution cannot be described classically in real time and opening the door to new types of quantum feedback control.

The photon and the vacuum cleaner

Ian A. Walmsley

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Quantum technologies based on optics often rely on photon bunching and measurement with feedforward to achieve an effective nonlinear interaction between otherwise transparent particles. The efficacy of this strategy for implementing nonlinear interactions requires pure state single photon wave packets. These, however, are not so easy to come by. In this talk I will discussed some methods and tools that enable the preparation of such state.

Long lived quantum memory with nuclear atomic spins

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[2] Laboratoire Kastler Brossel, Université Pierre et Marie Curie, Paris, France

We propose store non-classical states of light into the macroscopic collective nuclear spin (10^{18} atoms) of a ^{3}He vapor, using metastability exchange collisions. We show that these collisions currently used to transfer orientation from the metastable state 2^3S_1 to the ground state state of ^{3}He, may conserve quantum correlations and give a possible experimental scheme to perfectly map a squeezed vacuum field state onto a nuclear spin state, which should allow for extremely long storage times (hours). In addition to the apparent interest for quantum information, the scheme offers the intriguing possibility to create a long-lived non classical state for spins.

During a metastability exchange collision an atom in the ground state state and an atom in the metastable triplet state 2^3S exchange their electronic spin variables. The ground state atom is then brought into the metastable state and vice-versa. A laser transition is accessible from the metastable state so that the metastable atoms are coupled with light. This, together with metastability exchange collisions, provides an effective coupling between ground state atoms and light.

In our scheme, a coherent field and a squeezed vacuum field excite a Raman transition between Zeeman sublevels of the metastable state, after the system is prepared in the fully polarized state by preliminary optical pumping. According to the intensity of the coherent field, which acts as a control parameter, the squeezing of the field can be selectively transferred either to metastable or to ground state atoms. Once it is encoded in the purely nuclear spin of the ground state of ^{3}He, which is 20 eV apart from the nearest excited state and interacts very little with the environment, the quantum

state can survive for times as long as several hours. By lighting up only the coherent field in the same configuration as for the "writing" phase, the nuclear spin memory can be "read" after a long delay, the squeezing being transferred back to the electromagnetic field and measured.

“Random Lasers”

Gregor Hackenbroich, Fritz Haake

Fachbereich Physik, Universität Duisburg-Essen, Essen, Germany

Recent experiments on lasing by pumped disordered dielectrics without external mirrors require to generalize the standard quantum theory of the laser. Due to the absence of mirrors we must deal with “overlapping resonances” instead of modes of near ideal cavities. The disorder brings about new fluctuations, in addition to the familiar quantum optical ones and in a certain analogy to the conductance fluctuations in disordered electronic systems.

Quo vadis optica quantorum?

Maciej Lewenstein

ICFO – Institut de Ciències Fotòniques, Barcelona, Spain

In my talk I will present the recent developments of quantum optics, and in particular physics of ultra-cold gases that occur at the interplay between quantum optics, atomic physics, quantum information, statistical mechanics, condensed matter physics and even high energy physics, and touch the same frontiers and challenges of modern physics. In particular I will discuss the possibility of studying and discovering new phenomena in physics of frustrated anti-ferromagnets, and about possibility of studying some aspects of abelian and non-abelian gauge field theories.

Sudden entanglement death, and ways to avoid it

J.H. Eberly, **Ting Yu**

University of Rochester, Rochester, NY, USA

We report that non-communicating but entangled qubit pairs are almost universally liable to sudden entanglement death. In the presence of minor and purely local environmental noises their mixed-state entanglement may abruptly become zero long before the noises are able to destroy the local qubit coherence. Despite the inability of unitary transformations to alter entanglement, for example of Werner states, unitary transformations have been found to delay or defeat the sudden death event. These results upset the conventional understanding that entanglement lifetime can be estimated from qubit lifetime. This is not even approximately or qualitatively true.

LECTURES

Entanglement-enhanced communication over a quantum channel with correlated noise

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A. Dragan, W. Wasilewski, C. Radzewicz

Wydział Fizyki, Uniwersytet Warszawski, Warszawa, Poland

We present an experimental demonstration of entanglement-enhanced classical capacity of a quantum channel with correlated noise [1]. The channel is modelled by a fiber optic link exhibiting random birefringence that fluctuates on a time scale much longer than the temporal separation between consecutive uses of the channel. In this setting, it can be shown theoretically [2] that introducing entanglement between two photons travelling down the fiber allows one to encode reliably one bit of information into their polarization degree of freedom. When no quantum correlations between two separate uses of the channel are allowed, this capacity is reduced by a factor of more than three.

To demonstrate experimentally this effect, we generated polarization-entangled pairs of photons [3] in either a singlet or a triplet state, corresponding to the two values of a classical bit. The pairs were then launched into a single-mode fiber submitted to random mechanical movements, scrambling the polarization state of the travelling light. At the output of the fiber, the photon pairs were detected using the Braunstein-Mann Bell state analyzer [4] that allowed us to discriminate unambiguously the input singlet state against the triplet one despite polarization scrambling. To contrast this with the separable case, we also generated disentangled photon pairs and encoded information into their relative polarization. As predicted theoretically, after scrambling only partial information about the input state was retrieved.

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Manipulating photonic entanglement

Martin B. Plenio
Blackett Laboratory, Imperial College London, London, UK

I will review our work on photonic entanglement in the continuous variable regime including both Gaussian and non-Gaussian states. The feasibility and efficiency of various entanglement purification protocols are discussed this context.

Unconditional quantum cloning of coherent states with linear optics

Gerd Leuchs[1], **V. Josse**[2], **Ulrik L. Andersen**[1]

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[2] Institut d'Optique, Laboratoire Charles Fabry, Orsay, France

Intense light pulses with non-classical properties are used to implement protocols for quantum communication. Most of the elements in the tool box needed to assemble the experimental set-ups for these protocols are readily described by Bogoliubov transformations corresponding to Gaussian transformations that map Gaussian states onto Gaussian states. One particularly interesting application is quantum cloning of a coherent state. A scheme for optimal Gaussian cloning of optical coherent states is proposed and experimentally demonstrated. Its optical realization is based entirely on simple linear optical elements and homodyne detection. The optimality of the presented scheme is only limited by detection inefficiencies. Experimentally we achieved a cloning fidelity of about 65%, which almost touches the optimal value of 2/3.

Reference: arXiv:quant-ph/0501005.

Diatomic molecules in ultracold Fermi gases

Gora Shlyapnikov

Universiteit van Amsterdam, Van der Waals–Zeeman Instituut, Amsterdam, The Netherlands

I give a brief overview of recent studies of weakly bound homonuclear molecules in ultracold two-component Fermi gases. It is emphasized that they represent novel composite bosons, which exhibit features of Fermi statistics at short intermolecular distances. In particular, Pauli exclusion principle for identical fermionic atoms provides a strong suppression of collisional relaxation of such molecules into deep bound states. I then analyze heteronuclear molecules which are expected to be formed in mixtures of different fermionic atoms. It is found how an increase in the mass ratio for the constituent atoms changes the physics of collisional stability of such molecules compared to the case of homonuclear ones. I discuss Bose–Einstein condensation of these composite bosons and draw prospects for future studies.

Making manipulating and exploiting ultra-cold polar molecules

N.P. Bigelow, **C. Haimberger, J. Kleinert, M. Tscherneck, M.E. Holmes**

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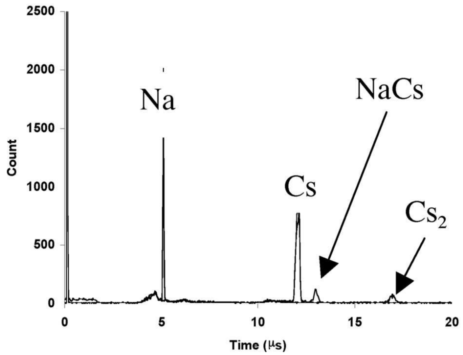
In the last 12 months several groups have demonstrated the use of photoassociation to create cold heteronuclear (polar) molecules. We report on the formation of translationally cold NaCs molecules starting from a laser-cooled atomic vapor of Na and Cs atoms. Colliding atoms are transferred into bound molecular states in a two-step photoactivated process. We find a translational temperature of $T \approx 260$ mK. To increase the density and number of trapped atoms, dark-spot techniques are used on the MOT and a Zeeman slowed sodium beam is used to load the sodium atoms into the trap. Spectroscopy of these molecules is underway using time-of-flight ion detection and trap-loss. Initial REMPI measurements indicate that both singlet and triplet states are being populated by the spontaneous-decay driven process. We measure a rate constant for molecule formation of $K_{\mathrm{NaCs}} = 7.43 \cdot 10^{-15}$ cm^3 s^{-1}.



Time of flight spectrum of REMPI signal from NaCs MOT

In a separate set of experiments, ultracold molecules have also been produced in a mirror magneto-optical trap that is part of an atom chip and these results will be described in this talk.

In this talk I will describe the "ultra-cold chemistry" of this process as well as progress towards applying these molecules to quantum information and polar-molecule Bose–Einstein condensates.

References from our group:
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Many-body dynamics of association in quantum gases

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Beer-Sheva, Israel

We study the dynamics of atom-molecule coupling through a Feshbach resonance in quantum degenerate gases of fermions and bosons. The fermionic problem in the single-molecular-mode and strong coupling approximations, transforms into the bosonic two-mode atom-molecule counterpart by mapping fermion holes to boson particles. Consequently, the dynamics of fermion association is mapped into the dynamics of boson dissociation, and shows a similar dynamical instability and boson-like collective behavior. Studying the dynamics of an adiabatic sweep through a Feshbach resonance in a quantum gas of fermionic atoms, we find that the dependence of the remaining atomic fraction on the sweep rate varies from exponential Landau–Zener behavior for a single pair of particles to a power-law dependence for large particle number. The power-law is linear when the initial molecular fraction is small compared to quantum fluctuations, and cube root when it is larger.

Two-mode theory of BEC interferometry

Brian J. Dalton

ARC Centre of Excellence for Quantum-Atom Optics
and Centre for Atom Optics and Ultrafast Spectroscopy,
Swinburne University of Technology, Melbourne, Australia

A theory of BEC interferometry in an unsymmetrical double-well trap has been developed for small boson numbers, based on the two-mode approximation. The bosons are initially in the lowest mode of a single well trap, which is split into a double well and then recombined. Possible fragmentations into separate BEC states in each well during the splitting/recombination process are allowed for. The BEC is treated as a giant spin system, the fragmented states are eigenstates of S^2 and S_z. Self-consistent sets of equations for the amplitudes of the fragmented states and for the two single boson mode functions are obtained. The latter are coupled Gross-Pitaevskii equations. Interferometric effects are measured via boson numbers in the first excited mode.

Images of a Bose–Einstein condensate: diagonal dynamical Bogoliubov vacuum

Jacek Dziarmaga, Krzysztof Sacha, Zbyszek Karkuszewski

Instytut Fizyki, Uniwersytet Jagielloński, Kraków, Poland

Evolution of a Bose–Einstein condensate subject to a time-dependent external perturbation can be described by a time-dependent Bogoliubov theory: a condensate initially in its ground state evolves into a time-dependent excited state which can be formally written as a time-dependent Bogoliubov vacuum annihilated by time-dependent quasiparticle annihilation operators. We prove that any Bogoliubov vacuum can be brought to a diagonal form in a time-dependent orthonormal basis. This diagonal form is taylored for simulations of quantum measurements on excited condensates.

As an example we work out a model of atomic interferometer where a trap potential is split in two parts by a potential barrier, and then atoms are released by opening the double-well trap potential. In the Gross–Pitaevskii approximation the released atoms give a high contrast interference pattern with repeatable position of interference fringes. In the two-mode tight-binding approximation the effect of phase diffusion makes the position of fringes fluctuate from experiment to experiment but every single realisation of experiment gives a high quality interference pattern. The time-dependent Bogoliubov theory is a more realistic description of the experiment which goes beyond both approximations. Using the diagonal time-dependent Bogoliubov vacuum we show that in addition to position fluctuations the interference pattern is also loosing its high quality contrast.

Coherence and correlations in a Mott insulator

Fabrice Gerbier, Artur Widera, Simon Fölling, Olaf Mandel, Tatjana Gericke, Immanuel Bloch

Institut für Physik, Johannes Gutenberg-Universität, Mainz, Germany

The observation of the superfluid to Mott insulator transition [1] has triggered an intense interest in studying ultracold quantum gases in optical lattices. Such a transition is commonly associated with the disappearance of the interference pattern observed when releasing a coherent (i.e. Bose condensed) ensemble from the lattice. In this talk, I will show that even in the insulating phase, the visibility of this interference pattern remains finite [2]. Our results show that although long-range order is absent, short-range coherence still persists in a rather broad range, and that this can be identified as a characteristic feature of the system for large, but finite lattice depths [3,4]. For even deeper lattices, the visibility is close to zero, and the interference pattern unobservable. I will explain that information is still present in such featureless images, and can be extracted by studying the density-density correlation function of the expanded cloud [5], as proposed theoretically in [6–8]. A sharp diffraction-like pattern observed in the correlations reveals the underlying lattice structure, and can be understood by generalizing the well-known Hanbury-Brown and Twiss effect to many bosonic sources "emitting" from each lattice site. This new detection method allows in principle the detection of spin ordering in a multi-component Mott insulator [6]. As a first step in this direction, we have recently observed spin dynamics in a Mott insulator [9], where a spin-dependent collisional coupling induces strongly underdamped Rabi oscillations between two-particle states with the same total magnetization. I will briefly report on these results.

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LECTURES

Ultracold chromium: a dipolar quantum gas

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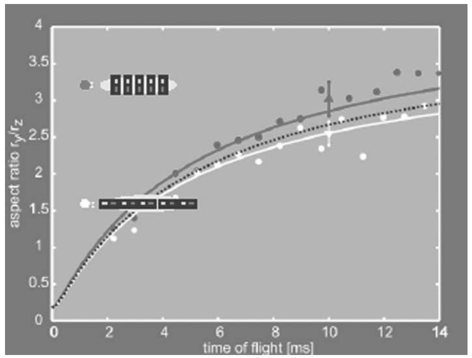
5th Institute of Physics, University of Stuttgart, Germany

We report on our recent achievement of a Bose–Einstein condensate in a gas of chromium atoms [1]. Peculiar electronic and magnetic properties of chromium require the implementation of novel cooling strategies. We observe up to $\approx 10^5$ condensed ^{52}Cr atoms after forced evaporation within a crossed optical dipole trap. Due to its large magnetic moment ($6\mu_{\mathrm{B}}$), the dipole-dipole interaction strength in chromium is comparable with the one of the van der Waals interaction. We prove the anisotropic nature of the dipolar interaction by releasing the condensate from a cigar shaped trap and observe, in time of flight measurements, the change of the aspect-ratio for different in-trap orientations of the atomic dipoles (see figure). We also report on the recent observation of 14 Feshbach resonances in elastic collisions between polarized ultra-cold ^{52}Cr atoms [2]. This is the first



Ballistic expansion of a dipolar quantum gas: The anisotropic interaction leads to a different expansion dynamics for the case of the magnetic dipoles aligned with the symmetry axis of the cigar shaped trap as compared with the dipoles oriented perpendicular to the axis of the cigar. The straight lines correspond to the theoretical expectation according to mean field theory without free parameters [3].

observation of collisional Feshbach resonances in an atomic species with more than one valence electron. Moreover, such resonances constitute an important tool towards the realization of a purely dipolar interacting gas because they can be used to change strength and sign of the van der Waals interaction.

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This work is supported by the priority programme SPP1116 of the German Research foundation (DFG).

Molecules and Cooper pairs in ultracold gases

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I will describe our theoretical work on molecular and Fermionic condensates relevant to recent experiments. These experiments use Feshbach resonances to tune the interactions between ultracold atoms. This has, in particular, enabled experimentalists to create molecular condensates from atomic ones. It has also made possible the creation of BCS-like Fermionic condensates. We have used a combination of cumulant dynamics and a separable potential approach to the binary collision process to produce a quantitative description of these experiments. I will focus on our theory of the BCS–BEC crossover observed potassium at JILA. Our theory gives a fairly complete picture of the relevant physics albeit at the mean-field level. I will discuss the prospects for developments in theory beyond mean-field theory.

Work supported by EPSRC, the EU and the Royal Society.

Fermi–Bose mixture of ^{40}K and ^{87}Rb atoms

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After the recent realization of the BCS–BEC crossover in dilute atomic Fermi gases, quantum degenerate mixtures of bosonic and fermionic atoms are expected to provide a complementary approach to fermionic superfluidity where the attractive interaction between Fermions is mediated by the interspecies interaction, a situation which is in many ways analogous to phonon-mediated Cooper pairing in superconductors. Moreover, these mixtures are expected to show a rich phase diagram when loaded into an optical lattice, with various pairing phases involving one or several fermionic and bosonic atoms. Already in a harmonic trap, these mixtures show a rich class of phenomena. The behaviour of the mixture is influenced by a lot of properties: mean field interaction both between Fermions and Bosons as well as the mean field interaction in the condensate. Depending on the sign of the Fermi–Bose interaction, phase separation or mean field trapping and collapse of the mixture are expected. The mass ratio between Fermions and Bosons will also influence the ratio of trapping frequencies between the two species. Three-body loss processes can have a dramatic impact on lifetime and dynamical behaviour of the mixture. The condensate overlapping only with a small part of the Fermi sea will introduce localized trapping and loss processes.

We report on the production of a quantum degenerate Fermi–Bose mixture of ^{40}K and ^{87}Rb in a regime of large particle numbers. In the experiment, we can span a wide range of phenomena starting at small particle numbers, where the expansion of the bosonic and the fermionic component are well described by the respective single-component Thomas–Fermi profiles. As particle numbers and densities in the mixture increase, the mean field attraction will create a strong localized mean field trapping potential in the centre of the trap where the BEC is localized. We observe this in-trap

effect as a bimodal distribution of the fermionic component in the axial direction after time of flight.

As the particle number is further increased we enter a regime of two competing effects: interspecies attraction dragging ^{40}K towards the centre of the trap, and three-body loss leading to a depletion of the Fermi cloud in the centre of the trap. At given trap frequencies and for particle numbers beyond certain critical values, the mixture collapses. This collapse happens on a rapid time scale in the centre of the trap, where the Fermi cloud overlaps with the BEC. As there is a reservoir of fermionic atoms outside the collapse region and as these atoms will remain localized in the outer region of the Fermi cloud on a time scale given by the (slow) axial trap frequency, the collapse region is “refilled” from the outer areas of the cloud and during the decay of the mixture, the collapse is expected to occur in several “revivals”. We have observed a step-like dependence of the atom number in the centre of the cloud as a function of time, supporting the idea of revivals of the collapse as observed in BECs with attractive interactions, but on a slower time scale due to the different “refilling” mechanism which involves the slow axial time scale. The critical particle numbers we observe for the onset of the collapse ($1.5 \cdot 10^6$ ^{87}Rb atoms in the condensate and $7 \cdot 10^5$ fermionic ^{40}K atoms at $\omega_{\rm rad} = 2\pi \cdot 257$ Hz and $\omega_{\rm ax} = 2\pi \cdot 11.2$ Hz) are in agreement with mean-field theory, relying on a recent precision measurement of the interspecies scattering length using Feshbach spectroscopy.

As the dimensionality is reduced into the quasi-1D regime, the mixture will be stabilized against collapse and bright solitonlike structures are expected to propagate in the ^{87}Rb BEC with repulsive interactions due to the attractive interaction with the fermionic component. Exploring and controlling the regime of high particle numbers is a prerequisite both for demonstration of these solitonlike structures and for controlling filling factors in large-volume 3D optical lattices.

Quantum computation with trapped ions

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[1] Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften
[2] Institut für Experimentalphysik, Innsbruck, Austria

Single Ca^+ ions and crystals of Ca^+ ions are confined in a linear Paul trap and are investigated for quantum information processing. Here we report on recent experimental advancements towards a quantum computer with such a system.

Laser-cooled trapped ions are ideally suited systems for the investigation and implementation of quantum information processing as one can gain almost complete control over their internal and external degrees of freedom. The combination of a Paul type ion trap with laser cooling leads to unique properties of trapped cold ions, such as control of the motional state down to the zero-point of the trapping potential, a high degree of isolation from the environment and thus a very long time available for manipulations and interactions at the quantum level. The very same properties make single trapped atoms and ions well suited for storing quantum information in longlived internal states, e.g. by encoding a quantum bit (qubit) of information within the coherent superposition of the $S_{1/2}$ ground state and the metastable $D_{5/2}$ excited state of Ca^+.

Recently we have achieved the implementation of simple algorithms with up to 3 qubits on an ion-trap quantum computer. We will report on methods to implement single qubit rotations, the realization of a two-qubit universal quantum gate (Cirac–Zoller CNOT-gate), the deterministic generation of multi-particle entangled states (GHZ- and W-states [1]), their full tomographic reconstruction, the realization of deterministic quantum teleportation [2], its quantum process tomography and the encoding of quantum information in decoherence-free subspaces with coherence times exeeding 20 seconds.

[1] C.F. Roos et al., *Science* **304**, 1478 (2004).
[2] M. Riebe et al., *Nature* **429**, 734 (2004).

Quantum theory of novel parametric devices

P.D. Drummond, M.D. Reid, K. Dechoum, S. Chaturvedi, M. Olsen, K. Kheruntsyan, A. Bradley

Australian Centre for Quantum Atom Optics,
The University of Queensland, Brisbane, Australia

While the parametric amplifier is a widely used and important source of entangled and squeezed photons, there are many possible ways to investigate the physics of intracavity parametric devices.

Novel quantum theory of parametric devices in this talk will cover several new types of unconventional devices, including the following topics:

- Critical intracavity paramp – We calculate intrinsic limits to entanglement of a quantum paramp, caused by nonlinear effects originating in phase noise of the pump.
- Degenerate planar paramp – We obtain universal quantum critical fluctuations in a planar paramp device by mapping to the equations of magnetic Lifshitz points
- Nondegenerate planar paramp – The Mermin–Wagner theorem is used to demonstrate that there is no phase transition in the case of a nondegenerate planar device!
- Coupled channel paramp – A robust and novel integrated entanglement source can be generated using type I waveguides coupled inside a cavity to generate spatial entanglement
- Cascade paramps – This possible “GHZ-type” source is obtained by cascading successive downconversion crystals inside the same cavity, giving two thresholds
- Parallel paramps – Tripartite entanglement can be generated if three intracavity paramp crystals are operated in parallel, each idler mode acting as a signal for the next.

Finally, we briefly treat the relevant experimental developments.

The Singapore protocol for quantum cryptography

Berge Englert

National University of Singapore

The qubit protocol for quantum key distribution presented in this talk is fully tomographic and more efficient than other tomographic protocols. Under ideal circumstances the efficiency is $\log_2(4/3) = 0.415$ key bits per qubit sent, which is 25% more than the efficiency of $1/3 = 0.333$ for the standard 6-state protocol. One can extract 0.4 key bits per qubit by a simple two-way communication scheme, and can so get close to the information-theoretical limit. The noise thresholds for secure key bit generation in the presence of unbiased noise will be reported and discussed.

Dynamics of a quantum phase transition

Wojciech H. Żurek

Theory Division, LANL, Los Alamos, NM, USA

We present two approaches to the non-equilibrium dynamics of a quench-induced phase transition in quantum Ising model. First approach retraces steps of the standard calculation to thermodynamic second order phase transitions in the quantum setting. The second calculation is purely quantum, based on the Landau–Zener formula for transition probabilities in processes that involve avoided level crossings. We show that the two approaches yield compatible results for the scaling of the defect density with the quench rate. We exhibit similarities between them, and comment on the insights they give into dynamics of quantum phase transitions.

Poster session I

1) Tomasz Świsłocki, Tomasz Karpiuk, Mirosław Brewczyk: Influence of nonlinearity on the superfluid transition in Bose–Fermi mixtures
2) Jan Chwedeńczuk: Quantum model for elastic scattering
3) Rafał Demkowicz-Dobrzański: State estimation on correlated copies
4) Piotr Deuar, Peter Drummond: First principles quantum simulations with 150 000 interacting Bose atoms in a colliding gas
5) Andrzej Dragan: Optimal coupling of down-conversion photon pairs to single-mode fibers
6) Emmanuel Courtade: Dynamics of atoms in a lattice of ring traps
7) Krzysztof Gawryluk, Mirosław Brewczyk, Kazimierz Rzążewski: Thermal instability of a doubly quantized vortex in a Bose–Einstein condensate
8) Iulia Ghiu, Anders Karlsson: Broadcasting of polarization entanglement at a distance using linear optics
9) S. Glancy, E. Knill: Error analysis for encoding a qubit in an oscillator
10) M.H. Szymańska, K. Góral, T. Köhler, K. Burnett: BCS–BEC cross-over in ultra-cold gases of ^{40}K
11) Andrzej Grudka, Antoni Wójcik: Probabilistic coding of quantum states
12) Y. Hasegawa, R. Loidl, G. Badurek, M. Baron, H. Rauch: Quantum contextuality in neutron interferometer experiments
13) S. Filipp, Y. Hasegawa, R. Loidl, H. Rauch: Quantum geometric phase
14) Zbigniew Idziaszek, Tommaso Calarco: Two ultracold atoms in an anisotropic harmonic trap
15) Lech Jakóbczyk, Anna Jamroz: Generation of Werner states and preservation of entanglement in a noisy environment
16) Ebrahim Karimi, Arashmid Nahal: New simulation of Zeeman cooling
17) Mohammad Amiri, Ebrahim Karimi: Anomalous behavior of wave near the focal point and near the line singularity in 1D phase step

18) Tomasz Karpiuk, Mirosław Brewczyk, Mariusz Gajda, Kazimierz Rzążewski: Bright solitons and stability–instability crossover in Bose–Fermi mixtures
19) Juergen Klepp: Pancharatnam phase in SU(2) neutron polarimetry
20) Konrad Banaszek, Piotr Kolenderski: Generation of spectrally uncorelated photon pairs by parametric down conversion
21) Jochen Kronjaeger, Christoph Becker, Martin Brinkmann, Kai Bongs, Klaus Sengstock: Evolution of spinor BEC in external fields
22) S. Kryszewski, J. Czechowska: On the positivity of collisional Bloch–Boltzmann eqautions
23) Anna Kubasiak, Jarek Korbicz, Jakub Zakrzewski, Maciej Lewenstein: Statistical physics in number theory
24) Antoni Wójcik, Tomasz Łuczak, Paweł Kurzyński, Andrzej Grudka, Tomasz Gdala, Małgorzata Bednarska: Quantum communication through spin chains
25) R. Chicireanu, A. Pouderous, B. Laburthe Tolra, E. Maréchal, L. Vernac, R. Barbé, J.C. Keller, O. Gorceix: Progress towards simultaneous magneto-optical trapping of fermionic ^{53}Cr and bosonic ^{52}Cr atoms
26) Koji Nagata, Wiesław Laskowski, Marcin Wieśniak, Marek Żukowski: Rotational invariance as an additional constraint on local realism
27) Farah Marsusi: Effective population inversion methods in a multiphoton absorption process
28) M. Barbieri, C. Cinelli, F. De Martini, P. Mataloni: Realization of the "all-versus-nothing" nonlocality test by adopting two-photon hyper-entanglement

Journal of Optics B: Quantum and Semiclassical Optics and *Journal of Physics B: Atomic, Molecular and Optical Physics* will sponsor two prizes, 50 euro each, for the best posters presented by graduate students. The prizes will be in the form of vouchers for books at Amazon.

Poster session II

29) Michał Matuszewski, Marek Trippenbach, Eryk Infeld: Dynamical stabilization of three-dimensional matter–wave solitons in periodic potentials
30) J. Dziarmaga, J. Meisner, K. Sacha: Soliton in BCS superfluid Fermi gas
31) Joshua Milstein, Keith Burnett: A molecular dynamics approach to understanding superfluidity
32) Ludmiła Praxmeyer, Krzysztof Wódkiewicz, Jan Mostowski: Wigner function for hydrogen atom
33) Bartłomiej Oleś, Krzysztof Sacha: Analytical soliton solution in a coupled atomic-molecular BEC
34) S. Ospelkaus, C. Ospelkaus, O. Wille, P. Ernst, M. Succo, K. Sengstock, K. Bongs: Quantum degenerate Fermi Bose mixture of ^{40}K and ^{87}Rb
35) Wiesław Laskowski, Tomasz Paterek, Marek Żukowski, Caslav Brukner: Tight multipartite Bell's inequalitites involving many measurement settings
36) Dominik Perykasza, Jan Mostowski, Krzysztof Wódkiewicz: States of hydrogen atom in phase space: classical picture
37) A. Grabowski, R. Heidemann, R. Loew, J. Stuhler, T. Pfau: Rydberg spectroscopy on cold Rb atoms
38) R. Parzyński, M. Sobczak, A. Plucińska: An iterative method for extreme optics of two-level systems
39) Jakub S. Prauzner-Bechcicki, Krzysztof Sacha, Bruno Eckhardt, Jakub Zakrzewski: Double ionization of O_2 molecules by short laser pulses
40) L. Praxmeyer, K. Wódkiewicz: Sub-Planck structures in phase space
41) Szymon Pustelny, Derek Kimball, Wojciech Gawlik, Dmitry Budker: Experimental realization of multidimentional "qubits"
42) V. Roscinski, W. Miklaszewski, J. Czub: Nonlinear magneto-optical rotation produced by atoms near $J = 1 \rightarrow J = 0$ transition
43) A. Raczyński, M. Rzepecka, J. Zaremba, S. Zielińska-Kaniasty: Coherent manipulation of stored light

44) Alice Sinatra: Long lived quantum memory with nuclear atomic spins
45) Iwo Białynicki-Birula, Tomasz Sowiński: Gravity-induced resonances in a rotating harmonic trap
46) Magdalena Stobińska, Krzysztof Wódkiewicz: Testing correlations in Kerr states
47) Ryszard Tanaś, Zbigniew Ficek: Entanglement of two atoms via squeezed vacuum
48) Genko Vasilev, Nikolay Vitanov: Coherent excitation of a two-state system by a Gaussian field
49) M. Grupp, G. Nandi, R. Walser, W.P. Schleich: Collective Feshbach resonances in a trapped two-component Bose–Einstein condesate
50) Wojciech Wasilewski, Alexander Lvovsky, Konrad Banaszek, Czesław Radzewicz: On the problem of squeezing eigenmodes in an optical parametric amplification
51) Roman Werpachowski, Jerzy Kijowski: Investigation of the trapped interacting 1D Bose gas with the block renormalization method
52) Antoni Wójcik: Quantum state transfer in spin networks
53) S. Kryszewski, M. Zachciał: Alternative representation for N-dimensional density operator (matrix)
54) Jakub Zakrzewski: Mean field approach to dynamics in 3D optical lattices
55) Łukasz Zawitkowski: Superfluidity in the classical fields approximation
56) Jakub Zieliński, Krzysztof Wódkiewicz: Degaussification of a Gaussian state
57) Paweł Ziń: Quantum model for elastic scattering
58) Władysław Żakowicz: A new glance at the electromagnetic and quantum wave scattering

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Monday, June 13

arrival

18:00 dinner

20:00 welcome party

sponsored by *Journal of Optics B: Quantum and Semiclassical Optics* and *Journal of Physics B: Atomic, Molecular and Optical Physics*

Tuesday, June 14

8:45 opening

9:00– 9:45 **Białynicki-Birula**
9:45–10:30 **Raymer**

10:30–11:00 coffee

11:00–11:45 **Deutsch**
11:45–12:30 **Walmsley**

13:00 lunch

15:15–16:00 **Sinatra**

16:00–16:30 coffee

16:30–17:15 **Haake**
17:15–18:00 **Lewenstein**

18:30 dinner

20:00 poster session I

Wednesday, June 15

9:00– 9:45 **Eberly**
9:45–10:30 **Banaszek**

10:30–11:00 coffee

11:00–11:45 **Plenio**
11:45–12:30 **Leuchs**

13:00 lunch

15:15–16:00 **Shlyapnikov**

16:00–16:30 coffee

16:30–17:15 **Bigelow**
17:15–18:00 **Vardi**

18:30 dinner

20:00 poster session II

PROGRAMME

Thursday, June 16

9:00– 9:45 **Dalton**
9:45–10:30 **Dziarmaga**

10:30–11:00 coffee

11:00–11:45 **Gerbier**
11:45–12:30 **Pfau**

13:00 lunch

15:00 excursion

19:00 conference dinner

Friday, June 16

9:00– 9:45 **Burnett**
9:45–10:30 **Sengstock**

10:30–11:00 coffee

11:00–11:45 **Häffner**
11:45–12:30 **Drummond**

13:00 lunch

15:15–16:00 **Englert**

16:00–16:30 coffee

16:30–17:15 **Żurek**

18:30 dinner

Saturday, June 18

departure