INTERNATIONAL CONFERENCE

Quantum Optics V

including The First Workshop of the Cold Quantum Gases European Community Network

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Abstracts of lectures
List of posters
Program

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Cooperative radiation and coherent trapping: the polarium model

R.J. Glauber

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In the absence of incoherent relaxation processes, the emission, absorption, and transport of resonance radiation by an extended medium are all processes in which the medium participates as a whole. By making appropriate approximations, we are able to describe the radiative interaction in terms of an integral equation with solutions that are easily found in closed form. We show, for the example of one-dimensional geometry, that the time-dependent electric polarization of the medium possesses a sequence of exponentially decaying normal modes that oscillate at frequencies slightly shifted from that of the fundamental atomic resonance. Only a small number of these modes are found to be strongly enough coupled to the electromagnetic field to be able to radiate efficiently. The remaining modes, an infinite sequence of them, are shown to radiate so slowly that they amount, in effect, to trapped fields. The spectra of the light emitted are shown to have multi-peaked resonant structures, and a frequency gap that becomes independent of the size of the medium and its initial polarization distribution for media that are sufficiently large. The same propagating and trapped modes and a generalization we call chevron modes are shown to play a simplifying role in the analysis of reflection and transmission of externally incident radiation by polarizable media.

Generation of photon number states by cavity quantum electrodynamics

Herbert Walther

Sektion Physik der Universität München and Max-Planck-Institut für Quantenoptik, Garching, Germany

In recent years there has been increasing interest in systems capable to generate photon fields containing a preset number of photons. This has chiefly arisen from applications for which single photons are a necessary requirement, such as secure quantum communication and quantum cryptography. Photon number states or Fock states are also useful for generating multiple atom entanglements in strongly coupled systems such as the micromaser. The generated field and the pumping atoms are in an entangled state, this entanglement can be transferred by the field to subsequent atoms, leading to applications such as basic quantum logic gates. For our experiments we employ a micromaser having a cavity Q of $4 \cdot 10^{10}$ corresponding to a photon lifetime of 0.3 s which is the largest ever achieved in this type of experiments. A source of single photons or, more generally, arbitrary Fock states is also a useful tool for further investigations of atom-field interaction. It can be used to obtain the reconstruction of purely quantum states of the radiation field as represented by the Fock states.

In this paper we give a survey of our experiments performed with the micromaser on the generation of Fock states. Three methods can be used for this purpose: the trapping states leading to Fock states in a continuous wave operation [1]; state reduction of a pulsed pumping beam [2] and finally using a pulsed pumping beam to produce Fock states on demand where trapping states stabilize the photon number [3]. With the latter method photon fields with small photon numbers can be generated with a probability of 97%.

[1] M. Weidinger, B.T.H. Varcoe, R. Heerlein, H. Walther, *Phys. Rev. Lett.* **82**, 3795 (1999).

[2] B.T.H. Varcoe, S. Brattke, M. Weidinger, H. Walther, *Nature* **403**, 743 (2000).

[3] S. Brattke, B.T.H. Varcoe, H. Walther, *Phys. Rev. Lett.*, in print.

Adiabatic approximations in laser-induced dynamic processes

Stig Stenholm

Physics Department, Royal Institute of Technology, Stockholm, Sweden

Adiabatic approximations are robust and efficient. Several recent dynamical processes have been described by evolution on time-dependent energy levels. Both in atomic and molecular physics such processes are utilized experimentally. In this talk we will concentrate on the corrections to adiabatic approaches, their scaling and the conditions for the validity of the approximation.

Nuclear fusion induced by super-intense ultra-short laser pulses in deuterium cluster plasma

Vladimir Krainov

Moscow Institute of Physics and Technology, Dolgoprodny, Russia

We review experimental data [1,2] and theory of the evolution of deuterium clusters irradiated by super-intense femtosecond laser pulses. Quick total *inner* ionization occurs at the leading edge of the laser pulse. For example, the spherical liquid cluster from deuterium molecules with the radius of 25 Å is transformed into plasma ball containing 3370 free electrons and 3370 deuterium nuclei. Further, all free electrons are ejected from the cluster by laser field also quickly at the leading edge of the laser pulse (*outer* ionization). Both inner and outer ionization are described by barrier-suppression mechanism [3,4]. Simultaneously the process of cluster expansion begins, first slowly, then quickly (this is so called Coulomb explosion). The final plasma in the laser focus presents a matter with the concentration of electrons and deuterons of order of 10^{19} cm^{-3}. Laser radiation penetrates through the whole plasma filament. The average kinetic energy of produced deuterons is of order of 1–2 keV. Then in this plasma the tunnelling nuclear reaction $\mathrm{d} + \mathrm{d} \rightarrow {}^3\mathrm{He} + \mathrm{n}$ takes place. In experiments [1,2] authors observed up to 10^4 neutrons per laser pulse. We suggest also to apply a SiO_2 – aerogel with gas density saturated by deuterium to induce nuclear fusion by a super-intense ultra-short laser pulse. The yield up to 10^5 neutrons per laser pulse is predicted for an aerogel irradiated by Ti:Sapphire laser pulse with the peak intensity of 10^{18} W/cm^2 and pulse duration of 35 fs.

[1] T. Ditmire et al., *Nature (London)* **398**, 489 (1999).
[2] J. Zweiback et al., *Phys. Rev. Lett.* **84**, 2634, **85**, 3640 (2000).
[3] V.P. Krainov, M.B. Smirnov, *Physics – Uspekhi* **43**, 949 (2000).
[4] V.P. Krainov, M.B. Smirnov, *JETP* **119**, No. 4 (2001).

Engineering entanglement in ultrafast photons

Ian Walmsley

The Institute of Optics, University of Rochester, Rochester, NY, USA

The ability to generate entanglement is a critical technology for quantum information processing. Optics provides a number of model systems for preparation of entangled states, though in many cases one cannot ignore the need to simulataneously manipulate the mode structure of the field. We discuss strategies for preparation and measurement of multimode entanglement in ultrashort optical pulses.

Engineering correlated photon pairs in nonlinear waveguides

Konrad Banaszek

University of Oxford, Clarendon Laboratory, Oxford, UK

Correlated photon pairs are a key ingredient of many protocols for quantum information processing. In order to achieve high-visibility interference between such photons, it is necessary to control precisely their spatio-temporal characteristics. Here we discuss spontaneous parametric down-conversion in nonlinear waveguides as a source of correlated photons in well defined modes. We present our recent experimental results, and review prospects of using this route to generate pairs of single-mode photons.

Quantum anti-centrifugal force

Wolfgang Schleich

Abteilung fuer Quantenphysik, University of Ulm, Ulm, Germany

In a two-dimensional world a free quantum particle of vanishing angular momentum experiences an attractive force [1]. This force originates from a modification of the classical centrifugal force due to the wave nature of the particle. For positive energies the quantum anti-centrifugal force manifests itself in a bunching of the nodes of the energy wave functions towards the origin [2]. For negative energies this force is sufficient to create a bound state in a two-dimensional delta function potential. In a counter-intuitive way the attractive force pushes the particle away from the location of the delta function potential. As a consequence, the particle is localized in a band-shaped domain around the origin. The quantum anti-centrifugal force also manifests itself in the propagator of the radial motion in two dimensions [3]. We compare this situation to the one- and three-dimensional case. A Wigner function treatment brings out most clearly the origin of this force.

[1] M.A. Cirone, K. Rzążewski, W.P. Schleich, F. Straub, J.A. Wheeler, 'Quantum anti-centrifugal force', *Phys. Rev. A* (2001).
[2] M.A. Cirone, G. Metikas, W.P. Schleich, 'Unusual bound or localized states', *Z. Naturforsch.* **56a**, 48 (2001).
[3] M.A. Cirone, J.P. Dahl, M. Fedorov, D. Greenberger, W.P. Schleich, 'Hygens principle, the free particle, and higher dimensions', *Acta Physica Slovaka* (2001).

On the extinction paradox

Władysław Żakowicz

Institute of Physics, Polish Academy of Sciences, Warsaw, Poland

The extinction paradox, the difference of classical and quantum scattering cross-sections ($\sigma^{\mathrm{Q}} = 2\pi a^2 = 2\sigma^{\mathrm{C}}$ for $ka \gg 1$), is analyzed. Rigorous solutions of the Schrödinger equation for particles' beams are illustrated and employed in the description of the scattering process. The classical limit of quantum scattering is established.

Phase control of bichromatically driven Rydberg atoms

Peter Koch

Department of Physics and Astronomy, State University of New York,
Stony Brook, NY, USA

We describe experiments exposing Rydberg atoms to short, intense pulses of a linearly polarized microwave field consisting of two phase-locked frequencies whose relative phase φ can be varied. Having used the same apparatus for experiments on two different atoms, we contrast their results. In experimental–theoretical work carried out with S. Zelazny and L. Sirko, helium atoms prepared in the $(1\mathrm{s}\, n\mathrm{s})\, {}^3\mathrm{S}_1$ Rydberg state with n near 30 were used to investigate how important φ is as a strong-field, quantum-control parameter when the frequency ratio $p\!:\!q$ is varied. The $p\!:\!q$ dependence has not been specifically addressed before experimentally, but it will become important when high-harmonic-generation sources driven by ultrashort-pulse lasers are developed as workaday laboratory tools. In experimental–theoretical work carried out with L. Sirko, hydrogen atoms prepared with, e.g., principal quantum number $n = 51$ were used to make the first study of the role of *common resonances* in ionization by microwave fields. These pendulumlike resonances require the presence of both driving frequencies. We demonstrate use of φ as a control parameter and use classical and quantal calculations to understand the phase sensitivity.

Double ionization in an intense laser field

Jan Chaloupka

Brookhaven National Laboratory, Upton, NY, USA

Neutral atoms interacting with intense laser fields can multiphoton ionize even for very low photon energies. Single electron ionization has been successfully modeled as the electron tunneling through the suppressed atomic Coulomb barrier. Double ionization, however, is more complex and must include two-electron correlation. We have studied the double ionization of helium and the other rare gases using an electron-ion coincidence technique. With this scheme, the electron energy spectrum correlated to the creation of a doubly charged ion may be compiled. In helium, the observed double ionization electron energy spectra differ significantly from the single ionization distributions. The dramatic enhancement at high electron energies gives new support to a quasi-classical rescattering model of double ionization. It also explicitly reveals the role of backward electron emission following the field-driven e-2e ionizing collision. In the other rare gases, similar but less striking differences between the single and double ionization electron distributions have been observed. We will present our latest results from these studies.

Universality of decoherence

Fritz Haake

Fachbereich Physik, Universität Essen, Essen, Germany

We consider environment induced decoherence of quantum superpositions to mixtures in the limit in which that process is much faster than any competing one generated by the Hamiltonian H_{sys} of the isolated system. While the golden rule then does not apply we can discard H_{sys}. By allowing for simultaneous couplings to different reservoirs, we reveal decoherence as a universal short-time phenomenon independent of the character of the system as well as the bath and of the basis the superimposed states are taken from. We discuss consequences for the classical behavior of the macroworld and quantum measurement: for the decoherence of superpositions of macroscopically distinct states the system Hamiltonian is always negligible.

On mixed-state entanglement and quantum communication

Paweł Horodecki

Technical University of Gdańsk, Faculty of Applied Physics and Mathematics,
Gdańsk, Poland

This is the brief description of the role of bipartite mixed-state entanglement in quantum communication. The effects of quantum teleportation, quantum cryptography with entangled states are briefly described. The idea of distillation of noisy entanglement is described, which was introduced to protect the effects against external noise. Various results concerning entanglement distillation are discussed including, in particular, irreversibility due to so called bound entanglement. Then notion of quantum channel is described. The close relation of entanglement distillation to quantum channels theory is explained and some recent results concerning the subject are presented.

Dark area theorem

Joseph Eberly

University of Rochester, Rochester, NY, USA

We will report the discovery of ‘dark area’ and describe the consequences of a ‘dark area theorem’. This is a previously unknown quantum optical relation allowing analytical predictions relevant to propagation of arbitrarily shaped short pump and Stokes pulses in coherently prepared Raman media. We will also derive a new equation predicting the spatial evolution of the atomic dark-state amplitude.

Communicating with single-photon 2-qubit states

Berthold-Georg Englert

Atominstitut, TU Wien, Wien, Austria

I'll discuss a scheme in which Alice sends single photons to Bob where, in marked contrast to other schemes, each photon is prepared in a 2-qubit state. One qubit is the photon polarization, for example, the other a spatial alternative. Each and every photon detected supplies one bit, no photon is wasted. The scheme can be used for secure key distribution and, provided that the detection efficiency is high enough, for direct secure communication.

Towards attosecond XUV pulses

Pierre Agostini

CEA/SPAM, CE Saclay, Gif-sur-Yvette, France

Several methods have been proposed to generate subfemtosecond XUV pulses. One of them is based upon high-harmonic generation obtained by focusing a femtosecond laser pulse in a gas jet: this can in principle produce a train of very short intensity spikes by their temporal beating. If this happens is crucially dependent on the relative phases of the harmonics. I will present a method to measure such phases through two-photon, two-color photoionization. Harmonics are indeed found locked in phase and form a train of 250 attosecond pulses thus proving to be a promising source for subfemtosecond time-resolved measurements.

Quantum control with ultrafast lasers

Philip Bucksbaum

Physics Department, University of Michigan, Ann Arbor, MI, USA

I will describe our recent progress to control quantum evolution of Rydberg wave packets using ultrafast THz electromagnetic fields.

Quantum cryptography with macroscopic nonclassical light

Michael Raymer

University of Oregon, Oregon Center for Optics, Eugene, OR, USA

We present a scheme for quantum key distribution using macroscopic, non-classical pulses of light. The sub-shot-noise nature of two-mode polarization-squeezed light provides the extreme sensitivity to the choice of measurement basis that is needed to prevent successful eavesdropping. The polarization-squeezed light is generated by using a seeded, Type-II optical parametric amplifier.

Non-classical state of a gas of atomic spins: approaches to entanglement

Nicholas P. Bigelow

University of Rochester, Department of Physics and Astronomy, Rochester, NY, USA

Entanglement is an essentially quantum mechanical property which is a signature of a non-classical state. In this talk I describe our work on the entanglement of a gas of atomic spins and of the resulting realization of a spin-squeezed state of the gas. In the first part of the talk, I will describe the creation of spin-squeezing via a QND-type state preparation approach as applied to a non-degenerate, thermal gas of atoms. In the second part of the talk, I will go on to show how a 'doubly quantum' gas can be created: the spin-squeezed Bose–Einstein spinor condensate.

Collisional avalanches in a Bose–Einstein condensate

Gerhard Rempe

Max-Planck Institute for Quantum Optics, Garching, Germany

Collisional avalanches are identified to be responsible for a dramatic decrease of the lifetime of a large Rb-87 condensate. Avalanches occur when the collisional opacity of an ultracold gas exhibits a critical value. When exceeded, losses due to inelastic collisions are substantially enhanced. Under these circumstances, reaching the hydrodynamic regime in conventional BEC experiments is highly questionable.

High T_c superfluidity in a quantum degenerate Fermi gas

Murray Holland

JILA, University of Colorado, Boulder, CO, USA

This talk will consider the superfluid phase transition that arises when a Feshbach resonance pairing occurs in a dilute Fermi gas. The theory will be applied to consider a specific resonance in potassium-40, and it will be shown that for achievable experimental conditions, the transition to a superfluid phase is possible at the high critical temperature of about $0.5\,T_{\mathrm{F}}$. Observation of superfluidity in this regime would provide the opportunity to experimentally study the crossover from the superfluid phase of weakly-coupled fermions to the Bose–Einstein condensation of strongly-bound composite bosons.

Solitons and vortices in Bose–Einstein condensates

Charles Clark

National Institute of Standards and Technology, Gaithersburg, MD, USA

Bose–Einstein condensation of an atomic gas involves a macroscopic number of the gas atoms occupying the same quantum state. Thus there is a condensate wavefunction (also called an order parameter), which manifests quantum mechanics on a macroscopic scale. I will discuss collective and topological excitations of the condensate that can be induced by manipulating the phase of this wavefunction. In the simplest picture of the dynamics of a condensate of interacting atoms, the wavefunction satisfies a Schrödinger-type equation (the Gross–Pitaevski equation) in which the potential contains a term proportional to the condensate density. This term, which derives from atomic interactions, thus gives rise to a nonlinear equation of motion for the wavefunction. This nonlinear Schrödinger equation is similar to that encountered in wave propagation in a nonlinear optical medium, and it has soliton solutions. These solutions have actually been produced in the laboratory by the 'imprinting' of a sharp variation of phase across the initial condensate wavefunction. The evolution of such solitons is simple only when the condensate is tightly confined in the two dimensions transverse to the motion of the soliton. When, as in most experiments, this is not the case, the soliton wavefront eventually breaks up. The first photographs of soliton decay showed the apparent generation of pairs of vortices with axes parallel to the soliton wavefront. These are now understood to have been two segments of a single vortex ring. Generation of vortex rings seems to be a typical mechanism of soliton decay, and indeed explicit images of vortex ring structure have been captured in recent experiments at JILA. Vortices can also be generated by rotating the condensate, and large (over 100 members) arrays of vortices have recently been observed at MIT. I will discuss results of recent simulations of such array structures in both isotropic and anisotropic harmonic traps.

Multiparticle entanglement in atomic systems

J. Ignacio Cirac

University of Innsbruck, Innsbruck, Austria

During the last few years it has been recognized that entangled states can lead to improvements in the fields of communication, computation, and precission measurements. In particular, they may lead to better atomic clocks. In this talk I will show how one can use Bose–Einstein condensates in order to obtain the atomic entangled states that are necessary for this last application.

POSTERS

1. Iwo Białynicki-Birula: Vortex lines in motion.
2. I. Carusotto, D. Embriaco, G.C. La Rocca: Reflection and transmission dynamics of coherent atomic pulses incident on optical lattices.
3. K.W. Chan, C.K. Law, J.H. Eberly: Control parameter for photon-atom entanglement in spontaneous emission.
4. Richard Conroy: An ultra-stable, broadly tunable source of yellow light.
5. Marek Czachor: Non-canonical quantum optics.
6. Andrzej Dragan, Konrad Banaszek: Homodyne Bell's inequalities for optical Schrödinger cat states.
7. Mikhail Fedorov: Interference stabilization in molecules.
8. Bożena Gadomska, Wojciech Gadomski: Homoclinic chaos in vibronic laser.
9. Markus Gangl: Cold atoms in optical resonators.
10. Wojciech Gawlik: Competition of dark-states: new optical resonances with anomalous magnetic field dependence.
11. R. Gębarowski, K.T. Taylor, D. Delande, J. Zakrzewski: Non-hydrogenic Rydberg atoms in circularly polarized microwaves.
12. Sergei Goreslavski: Nonsequential double ionization: dependence of the momentum distributions on laser intensity.
13. V.V. Gridchin, A.M. Popov, O.V. Smirnova: Coulomb explosion of diatomic heteronuclear molecules in a strong laser field.
14. Andrzej Grudka: Effect of extra resonances in the Rydberg-to-Rydberg Raman migration.
15. Maciej Janowicz: Time-dependent wave propagation in a pumped photonic crystal.
16. Piotr Kochański, Iwo Białynicki-Birula, Zofia Białynicka-Birula: Cavity Trojan wave packets and spontaneous symmetry breaking.
17. Marek Kuś: Separable approximations for mixed states of composite quantum systems.
18. Wiesław Miklaszewski: The higer order corrections to the adiabatic approximation for an atom interacting with light.
19. Prot Pakoński, Karol Życzkowski: Infinite families of topologically conjugated digraphs.
20. R. Parzyński, M. Sobczak, A. Wójcik: Photoionization artifacts from model Rydberg atoms.
21. Tilman Pfau: A new multimode waveguide – interferometer.

22. Alexander Popov: Laser-induced ionization and fragmentation of diatomic molecules.
23. Ludmila Praxmeyer: Quantum interference in the Kirkwood–Rihaczek representation.
24. Marian Rusek, Arkadiusz Orłowski, Jan Mostowski: Scattering of light by random media – model studies.
25. Krzysztof Sacha: Chaotic H atoms may reveal linear, quadratic or even quartic level repulsion.
26. Krzysztof Sacha: Wannier threshold law for two electron escape in the presence of an external electric field.
27. Leszek Sirko: Use of the relative phase in a bichromatic field to control a quasienergy gap.
28. Dmitry Strekalov: Two-photon interferometry for high-resolution imaging.
29. Olga Tikhonova: Stabilization of the three-dimensional quantum system with a short-range potential.
30. Krzysztof Wódkiewicz: Classical and quantum teleportation protocols.
31. Boris Zakhariev: Inverse problem lessons on quantum intuition (in pictures).

Microscopic magnetic guides and traps for cold atoms

E.A. Hinds, **C. Vale, B. Hall, D. Lau, M. Jones, J. Retter**

SCOAP, University of Sussex, Brighton, UK

We are confining cold atoms to long thin traps made by magnetic fields. Atoms can be propagate along these guides and the guiding potentials themselves can be moved. These provide a basis for making atom interferometers and atom chips. I will report on experimental progress at Sussex in this subject.

Investigation of the low lying collective modes of a condensate

Eleanor Hodby

Atomic and Laser Physics Department, University of Oxford,
Clarendon Laboratory, Oxford, UK

The spectrum of discrete excited states of a Bose Einstein condensate contains vital information about these novel quantum objects, in the same manner that electronic energy levels reveal the structure of an atom. In the linear hydrodynamic theory of BEC, this spectrum depends strongly on the geometry of the trap that confines the atoms. At Oxford we have developed new methods for modifying the geometry of our TOP trap, enabling us to excite these low lying collective modes and explore the interactions between them. This talk will summarise our research over the past year, which has covered the scissors mode, up-conversion processes and Beliaev coupling.

Cold collisions in Rb MOT

Witold Chałupczak

Institute of Physics, UJ, Kraków, Poland

Results of recent experiments on cold collisions will be presented. In particular, the differential measurements which allow the extraction of the rate of the fine structure changing collisions and radiative escape will be discussed. Application of nonlinear absorption and four-wave mixing methods for the trap diagnostics will be addressed.

What tunneling of Bose–Einstein condensates has to do with polaron physics

V.M. (Nitant) Kenkre

Department of Physics, University of New Mexico, Albuquerque, NM, USA

The formal similarity of the Gross–Pitaevskii equation and the nonlinear Schrödinger equation allows a number of useful bridges to be built across the otherwise unrelated areas of Bose–Einstein condensation and polaron physics. The connections will be illustrated in the context of a simple model of the tunneling of a condensate.

Weak localization of light with cold atoms

Christian Miniatura

Laboratoire Ondes et Désordre, Valbonne, France

We shall present our recent experimental and theoretical results about coherent backscattering (CBS) of light by cold atoms. CBS is an interferential enhancement of the average diffuse intensity reflected off the scattering sample in the backscattering direction. It is a hallmark of interference effects in multiple scattering known to inhibit wave transport in disordered media. CBS has been well studied for classical scatterers. However the use of atoms as scatterers raises new questions. We shall discuss these points and we shall show how the internal structure of atoms is responsible for a severe decrease of the CBS interference as confirmed by experiment.

BEC in an optical lattice

Kristian Helmerson

National Institute of Standards and Technology, Gaithersburg, MD, USA

We have demonstrated adiabatic loading of a BEC into the lowest energy band of a 1-D optical lattice. We can subsequently drive optical Raman transitions to transfer population to other bands of the lattice. We are investigating the use of atoms in lattices for quantum information and quantum chaos studies.

Rb condensates in 1-D optical lattices

Joerg Helge Mueller

INFM UdR Universita di Pisa, Dipartimento di Fisica, Pisa, Italy

We loaded Bose Einstein condensates of Rb atoms into 1-dimensional optical lattices and studied the dynamics of the atoms. Accelerating the periodic potential by scanning the frequency difference between the two laser beams forming the lattice we observed Bloch oscillations in the center of mas motion of the condensate. When the lattice depth is reduced atoms are allowed to tunnel into the continuum during the acceleration. The exponential dependence of the tunneling rate on lattice depth and acceleration can be used as a sensitive probe for modifications of the potential due to the interaction between the atoms. In a simple perturbative model the meanfield of the condensate provides a penalty for density modulation leading to a reduced effective potential of the lattice. We studied the density dependence of the effective lattice potential for different lattice geometries confirming the predictions of the simple model for moderate condensate densities.

BEC in optical lattice

Marek Trippenbach

Warsaw University, Warsaw, Poland

We study the dynamical problem of the optical lattice imposed of the Bose Einstein condensate, in the view of the possible application to the quantum computers. In the simple one dimensional model we address the issues of adiabaticity and coherence of the condensate in the lattice which amplitude is a slowly varying function of time. We give the prescription of how the optical potential should be raised to preserve adiabaticity in the linear case (neglecting atom–atom interactions). We present numerical simulations of the condensate behaviour in such an optical lattice when nonlinearity originating from atom–atom interactions is included.

Writing and trapping experiments with chromium

Tilman Pfau

University of Stuttgart, 5th Institute of Physics, Stuttgart, Germany

We have used optical lattices to write various structures with thermal chromium beam onto a substrate. The material-selectivity of the atom light interaction is used to structure the material composition during growth. Resulting samples with a structured doping profile might find applications as photonic crystals. We have also realized a scheme for loading ultracold chromium atoms continuously into a magnetic trap. We trap 10^8 atoms at sub Doppler temperatures at loading rates of 10^8 atoms per second. Various collisional properties of the chromium atoms are investigated. The magnetic trap provides good starting conditions for further evaporative cooling.

Bose Einstein condensation in ^{85}Rb – the key to cracking caesium?

Simon Cornish

University of Oxford, Clarendon Laboratory, Oxford, UK

Near a Feshbach resonance the inter-atomic interactions in a dilute alkali gas can be adjusted at will by simply changing the magnetic field. The ability to control the interactions in this manner proved crucial in the achievement of Bose Einstein condensation in ^{85}Rb. The observation of several Feshbach resonances in Cs suggests a similar experimental approach may be the key to successfully condensing this most stubborn of alkalis. I will present details of the ^{85}Rb experiment at JILA, highlighting the role of the Feshbach resonance, and will report the development of a new Cs experiment at Oxford designed to exploit the collisional properties in the vicinity of a Feshbach resonance.

Experimental observation of quantum degeneracy in fermionic Li

Lev Khaykovich

Laboratoire Kastler Brossel, Ecole Normale Supérieure, Paris, France

Using a technique of sympathetic cooling of fermionic isotope of Li atoms by its bosonic counterpart, we have been able to produce a gas of fermions well into the degenerate regime. Temperatures of fermions as small as $0.3\,T_{\mathrm{Fermi}}$ have been obtained, and the onset of quantum degeneracy has been observed both in position and in momentum space via direct comparison with the corresponding distributions of bosons at the same temperatures. In position space the difference in the sizes of fermions and bosons gives direct observation of Fermi pressure, while the comparison in the momentum space shows the difference in energy of both isotopes. The contribution of the boson–fermion mean field interaction and modification of the boson–fermion collisional dynamics in the quantum degenerate regime will be discussed. Finally, using a tightly confined magnetic trap, we have obtained high Fermi energies which exceed the recoil energy of Li atoms. This opens the possibility to investigate an inhibition of light-scattering events in Fermi gases.

Progress in cooling and trapping of metastable helium

Norbert Herschbach

Vrije Universiteit Amsterdam, Amsterdam, Holland

We are cooling and trapping metastable triplet helium atoms with the goal to achieve a density of atoms in a Ioffe magnetic trap which is high enough for runaway evaporative cooling and to reach Bose–Einstein condensation. We have developed a magneto-optical trap (MOT) containing 10^9 atoms with a central density of $4 \cdot 10^9$ cm^{-3} and a temperature of 1 mK. As Penning and associative ionisation in optical collisions infer high loss rates, a large red detuning for the MOT laser of 20 times the transition linewidth and a large loading rate of $5 \cdot 10^9$ atoms/s are required. With a liquid nitrogen cooled dc discharge source and a collimation and deflection section we produce a collimated and pure beam of metastable atoms. This beam is decelerated in a two-part Zeeman slower and loads the MOT. We have investigated Penning ionisation in optical collisions and photo-association resonances have been found. Also the Penning ionisation rate constant in absence of light was measured and a reduction of the ionisation rate was observed when the atomic cloud is spin polarised.

Prior to the recapture in the magnetic trap, a temperature around 0.3 mK is reached with an extra Doppler molasses pulse applied to the atomic cloud released from the MOT. In the quadrupole magnetic trap we observe by absorption imaging the exponentially cusped density distribution characteristic for this trap. Also evidence for rf-induced evaporative cooling is found. Losses due to Majorana spin-flips are known to occur in quadrupole magnetic traps. And they are large in systems with small atomic mass even at relatively high temperatures. The deterioration of the trap lifetime due to these losses is clearly measurable and prevents runaway evaporative cooling. Our Ioffe magnetic trap has a cloverleaf geometry and its implementation allows for absorption imaging of the atomic cloud as well as the detection of metastable atoms and ions with micro-channel plate detectors. Currently we are optimising the recapture of the cloud in the Ioffe magnetic trap and hope to reach runaway evaporative cooling soon.

Bose–Einstein condensation of a metastable helium gas

J. Léonard, F. Pereira Dos Santos, Junmin Wang, F. Perales, C. Barrelet, M. Leduc, C. Cohen-Tannoudji

Laboratoire Kastler Brossel, Département de Physique
de l'Ecole Normale Supérieure, Paris, France

I will present a recent breakthrough in our group: a Bose–Einstein Condensate (BEC) of helium ($^4He^*$) atoms in the metastable triplet state. We observed an inversion of the ellipticity of the cloud as the expansion time increases. This is evidence for the crossing over the BEC transition.

A helium beam in the 2^3S_1 metastable state is produced by an electronic discharge. It is then collimated and deflected using the radiation pressure of a resonant laser beam locked on the 2^3S_1–2^3P_2 transition at 1.083 μm. The velocity of the atomic beam is reduced down to 50 m/s with the Zeeman slowing technic. At this velocity, this atomic beam can be used to load a Magneto-Optical Trap (MOT) where we trap up to 10^9 atoms, at a temperature of approximately 1 mK. The atomic density in the MOT is limited by inelastic Penning collisions between metastable helium atoms, which are dominant in a non-polarised sample in the presence of light.

One third of these atoms are transfered in a magnetic trap designed in a Ioffe-Pritchard configuration. Because of the polarisation of the magnetically trapped atoms, Penning collisions are strongly reduced. The life time of the cloud in the magnetic trap can reach up to 90 s.

Finally the cloud undergoes evaporative cooling which consists of removing high velocity atoms. Elastic collisions between remaining atoms redistribute the total energy in the cloud leading to a decrease in temperature. The phase space density of the cloud increases up to the Bose–Einstein transition that occurs at a temperature of approximately 4 μK. Our detection scheme consists of absorption imaging on a CCD camera at 1.083 μm. We were able to give an estimation of the scattering length a of $^4He^*$ ($a = 16 \pm 8$ nm) and to give an upper boundary of the inelastic collision rate constants.

In future work, we plan first to improve the accuracy of the previous measurement, and then to study the hydrodynamic regime above the critical temperature. Indead, the high scattering length of $^4He^*$ and the atomic density obtained give rise to an interesting regime were the mean free path is much smaller than the size of the cloud.

Bose–Einstein condensation using metastable helium atoms

C.I. Westbrook, A. Robert, O. Sirjean, A. Browaeys, A. Aspect

Institut d'Optique, Centre Universitaire d'Orsay, Orsay, France

The talk will discuss our recently successful attempt to observe BEC in metastable helium (He*). We use a Zeeman cooling apparatus and a magneto-optical trap to load He* into a cloverleaf-type magnetic trap. In this trap, a RF evaporation ramp cools atoms from 1 mK to 1 μK, at which temperature we observe BEC formation with about 10^5 atoms. A novel feature of the experiment is that all detection is done with a microchannel plate (MCP), placed below the trap. This detector allows us to perform time of flight measurements after releasing the atoms, as well as monitoring the flux of ions from the trap. This flux is high enough to permit continuous 'real time' monitoring of the trapped atoms. We observe the creation of the BEC, as well as its decay, both on a time scale of 0.1 s to a few s.

Linear and nonlinear atom optics with BEC in 1D-regimes

Klaus Sengstock

Institut fuer Quantenoptik, Universitaet Hannover, Hannover, Germany

The realization of Bose–Einstein condensation (BEC) of weakly interacting atomic gases strongly stimulates the exploration of nonlinear properties of matter waves. This supports the field of nonlinear atom optics as well as the study of various types of excitations. Of particular interest is the change of the dynamics of BEC in lower dimensions, e.g., the dissipation properties of excited states in reduced dimensions. In this paper we concentrate on the physics of BEC in 'quasi-1D' geometries and in the strong 1D regime. We will discuss experimental results on the dynamics of soliton-states of BEC as well as matter wave guiding and interferometry in different conditions of 1D-geometries.

Vortex–sound interactions in Bose–Einstein condensates

Charles Adams

Durham University, Department of Physics, Durham, UK

Stirring a Bose–Einstein condensate can produce a highly excited state containing both vortices and sound. After excitation the vortex density decreases due to sound emission from vortex reconnections and vortex motion. This process is analogous to the decay of superfluid turbulence in liquid helium. We will discuss the formation of superfluid turbulent states, and sound emission due to vortex reconnections and vortex motion.

Stochastic field methods for the interacting Bose gas

Iacopo Carusotto, **Yvan Castin**, **Jean Dalibard**

Laboratoire Kastler Brossel, Ecole Normale Supérieure, Paris, France

In the present work we shall give an overview of the different stochastic field methods that can be used to simulate the exact time evolution of an interacting Bose gas. The representation of a quantum Bose field in terms of quasi-probability distribution functions has been one of the most fruitful tools in quantum optics, since it allows to reformulate the master equation for the density operator into a Fokker–Planck-like equation for the quasi-probability distribution. Thanks to the fundamental analogy between the electromagnetic field and the matter field, such techniques are now starting to be applied to study the dynamics of atomic Bose–Einstein condensates. In order for the Fokker–Planck equation to be simulated by means of a simple Brownian motion, no term involving third order derivatives has to be present and the diffusion term has to be positive; unfortunately this is not the case for the Glauber-P, nor for the Q, nor for the Wigner-W representations. More complex representations involving a pair of stochastic fields instead of a single field have therefore been developed in order to make such simulations possible. The positive-P representation has been the first example of such schemes, but its intrinsic instability makes its pratical application to atomic Bose–Einstein condensates very difficult. We have developed a more general approach to the interacting Bose gas problem in terms of the stochastic evolution of Hartree ansatz of the form $\rho = |\mathrm{N}\colon \phi_1\rangle\langle \mathrm{N}\colon \phi_2|$ or $\rho = |\mathrm{coh}\colon \phi_1\rangle\langle \mathrm{coh}\colon \phi_2|$ where the macroscopic wavefunctions $\phi_{1,2}$ evolve according to a pair of stochastic differential equations [1]. As a particular solution, we recover the stochastic scheme corresponding to positive-P representation. Thanks to the generality of the approach, other schemes can be found which are proven to be immune from instability problems and whose application is only limited by computational power. We are currently exploring a new direction, consisting in developing a new scheme for the numerical simulation of Fokker–Planck equations involving non-positive diffusion terms or third-order derivative terms: a single field, rather than a pair of conjugate fields, is evolved, but the stochastic evolution is no longer a simple Brownian motion. In this way a simulation of the exact quantum dynamics is possible within the Glauber-P, Q as well as Wigner-W representations.

[1] I. Carusotto, Y. Castin, J. Dalibard, *Phys. Rev. A* **63**, 023606 (2000).

Interaction processes in a mixture of ultracold gases

Allard Mosk

MPI fuer Kernphysik, Heidelberg, Germany

We investigate elastic and inelastic collisions between ultracold lithium and cesium atoms which are trapped in a quasi-electrostatic dipole trap (QUEST). The QUEST, which consists of a focussed 100 W CO_2 laser, is ideal for studying these processes as its trapping potential is independent of the hyperfine state of the atom. Indeed, depending on the hyperfine state of the atoms we see either inelastic losses or evidence for cross-thermalization of the two gases. This thermalization may be used to sympathetically cool the Li to high phase space density using sub-Doppler cooled Cs. The sympathetically cooled gas mixture is a good starting point for creation of ultracold heteronuclear molecules. For slightly higher temperatures, the thermalization is accompanied by evaporation of the more weakly trapped Li atoms. In this case the sympathetic cooling appears reversed: the hot Li gas cools the cold Cs. A simplified thermalization model agrees well with our data.

Coherence of Bose–Einstein condensate

Mariusz Gajda

Institute of Physics, Polish Academy of Sciences
and College of Science, Warsaw, Poland

We study an exactly solvable system of trapped bosonic particles interacting by model harmonic forces. Relation between the order parameter (or off-diagonal-long-range order) and coherence of a Bose–Einstein condensate is discussed.

POSTERS

1. Grzegorz Andrelczyk, Mirosław Brewczyk, Łukasz Dobrek, Mariusz Gajda, Maciej Lewenstein: Optical generation of vortices in trapped Bose–Einstein condensates.
2. Jan Arlt, Pasi Ryytty: Studies of Bose–Einstein condensation in quasi 1D geometries.
3. Radka Bach, Marek Trippenbach, Kazimierz Rzążewski: Spontaneous emission losses during two condensates collision.
4. Joachim Brand: Dark soliton creation in Bose–Einstein condensates.
5. Joachim Brand: Solitonic vortices in the mean-field theory for the BEC.
6. Mirosław Brewczyk, Kazimierz Rzążewski: Vortices and solitons in ultracold fermionic gases.
7. S. Burger, F.S. Cataliotti, C. Fort, F. Minardi, M. Inguscio: Bose–Einstein condensates in a 1D optical lattice.
8. P. Donaldson, C. MacCormack, S. Hopkins, E. Hinds, M. Boshier: In situ magnetic trapping of Bose condensates.
9. J.H. Eberly, Q.-H. Park: Interference oscillations in a tilted box: two-component BEC dynamics.
10. B. Eiermann, T. Anker, K. Forberich, B. Brezger, M.J. Bellanca, J. Mlynek, M.K. Oberthaler: Bright atomic solitons for repulsive atom-atom interaction.
11. Filip Floegel: Continuous optical loading of a Bose–Einstein condensate.
12. Simon Gardiner: Cavity assisted quasi-particle damping in a BEC.
13. Roman Gielerak: Poisson–Wiener integral representation of the Bose matter.
14. Roman Gielerak: Thermofield-like perturbation of the ideal Bose gas.
15. Rachel Godun: Experiments with quantum accelerator modes.
16. Krzysztof Góral, Mariusz Gajda, Kazimierz Rzążewski: Multimode description of an interacting Bose–Einstein condensate.
17. Krzysztof Góral, Mariusz Gajda, Kazimierz Rzążewski: Multimode dynamics of a coupled ultracold atomic-molecular system.
18. Markus Greiner: Exploring phase coherence in a 1D, 2D and 3D lattice of Bose–Einstein condensates.
19. Lucia Hackermüller: Getting in touch with an interference pattern – lithographical methods.
20. Eleanor Hodby: Investigation of the low lying collective modes of a condensate.
21. Zbigniew Idziaszek, Kazimierz Rzążewski: Statistical properties of Bose–Einstein condensate in an optical lattice.

22. Maciej Janowicz: Quantum Monte Carlo simulation of many particles in a harmonic trap.
23. Svante Jonsell: Two- and three-body interactions between cold trapped bosons with long scattering lengths.
24. Allard Mosk: Fermionic lithium atoms in a resonator-enhanced optical dipole trap.
25. C. Mueller, T. Jonckheere, R. Kaiser, Ch. Miniatura, D. Delande: Weak localization of light in cold atoms.
26. Olaf Nairz, Björn Brezger, Lucia Hackermüller, Markus Arndt, Anton Zeilinger: Interference of the fullerenes C_{60} and C_{70} at an optical grating.
27. Belen Paredes: 1/2 anyons in small atomic Bose–Einstein condensates.
28. Dmitry Petrov: BCS transition in quasi-2D Fermi gases.
29. Tilman Pfau: An intense 2D MOT source of cold Rb atoms.
30. Alice Robert: Bose–Einstein condensation of metastable He.
31. Luis Santos: Solitons and vortices in two-component Bose–Einstein condensates.
32. Gergely Szirmai: The structure of the perturbation series of the spin-1 Bose gas.
33. Lorenzo Vichi: Damping of low energy excitations in Bose condensed gases.
34. Chris Westbrook: Coherent reflection from an atomic mirror.
35. Jerzy Zachorowski: Atomic recoil and localization effects in MOT.
36. Jakub Zakrzewski: Yet another way to collectively excite BEC.
37. Magdalena A. Załuska-Kotur, Mariusz Gajda, Arkadiusz Orłowski, Jan Mostowski: Exact versus mean-field description of the Bose–Einstein condensate: a model study.
38. Paweł Zin, Andrzej Dragan: Dynamics of formation of a Bose–Einstein condensate of metastable helium atoms.

SOCIAL PROGRAM

Wednesday, June 20, 19:00
Welcome party

Sunday, June 24
Excursion to Kraków and salt mine in Wieliczka

Monday, June 25, 20:00
Banquet

MONDAY June 25	**TUESDAY** June 26	**WEDNESDAY** June 27
	8:00 Breakfast	8:00 Breakfast
	9:15–10:45 **Helmerson** **Mueller** **Trippenbach**	9:15–10:45 **Carusotto** **Mosk** **Gajda**
	10:45–11:15 Coffee	10:45–11:15 Coffee
	11:15–12:45 **Pfau** **Cornish** **Khyakovich**	
	13:00 Lunch	13:00 Lunch
	15:45–16:15 Coffee	
16:15–17:45 **Hinds** **Hodby** **Chałupczak**	16:15–17:45 **Herschbach** **Léonard** **Westbrook**	
17:45–18:15 Coffee	18:00 Dinner	
18:15–19:15 **Kenkre** **Miniatura**	19:00–20:00 **Sengstock** **Adams**	
20:00 Banquet	20:30 **Poster session**	

THURSDAY June 21	**FRIDAY** June 22	**SATURDAY** June 23	**MONDAY** June 25
8:00 Breakfast	8:00 Breakfast	8:00 Breakfast	8:00 Breakfast
9:00–10:00 **Glauber**	9:00–10:00 **Schleich**	9:00–10:00 **Eberly***	9:00–10:00 **Rempe**
10:00–10:45 **Walther**	10:00–10:45 **Żakowicz**	10:00–10:45 **Englert**	10:00–10:45 **Holland**
10:45–11:15 Coffee	10:45–11:15 Coffee	10:45–11:15 Coffee	10:45–11:15 Coffee
11:15–12:00 **Stenholm**	11:15–12:00 **Koch**	11:15–12:00 **Agostini**	11:15–12:00 **Clark**
12:00–12:45 **Krainov**	12:00–12:45 **Chaloupka**	12:00–12:45 **Bucksbaum**	12:00–12:45 **Cirac**
13:00 Lunch	13:00 Lunch	13:00 Lunch	13:00 Lunch
15:45–16:15 Coffee	15:45–16:15 Coffee	15:45–16:15 Coffee	
16:15–17:00 **Walmsley**	16:15–17:00 **Haake**	16:15–17:00 **Raymer**	
17:00–17:45 **Banaszek**	17:00–17:45 **Horodecki**	17:00–17:45 **Bigelow**	
18:00 Dinner	18:00 Dinner	18:00 Dinner	
	19:30 **Poster session**		20:00 Banquet

* Journal of Physics B lecture