European Science Foundation

Standing Committee for Physical and Engineering Sciences (PESC)

ESF/PESC EXPLORATORY WORKSHOP

CATS

Collisions in Atom Traps

Sunday 7th to Thursday 11th April 2002

Sandbjerg Manor

Sandbjerg Gods, DK-6400 Sønderborg, Denmark

Collisions in Atom Traps (CATS)

Scientific programme

The ability to cool trap and manipulate atoms, culminating in the successful formation of Bose-Einstein Condensates (BEC), is one of the most exciting advances in the field of atomic and molecular physics in the late 20th century. Such experimental advances are pioneering the construction of new instrumentation at both the atomic and nanoscale (e.g. the development of atomic interferometers) and has led to orders of magnitude improvement in our ability to measure time while opening the possibility of developing the new technologies of atom lasers, quantum computing, quantum cryptography and teleportation.

To date the role of collisions in atom traps has been viewed mainly as detrimental - leading to trap losses- but recently experiments and new theoretical formalisms suggest that collisions between trap atoms, between trapped atoms and external stimulation phenomena and between cold atoms and external surface media may lead to new physico-chemical phenomena that may in turn lead to exciting new fields of study in atomic, molecular, optical and condensed matter physics. For example in photo-association spectroscopy excited bound molecular states are created for free atoms by using a laser photon to form alkali dimers suitable for high resolution spectroscopic measurements.

In this workshop we bring together experts in the fields of trapped atoms, laser physics, collision physics, spectroscopy and condensed matter to discuss future studies of collisional phenomena in atom traps. The meeting is arranged in seven scientific sessions with six sessions dedicated to the presentation of plenary talks to be followed by discussion. The last session will be dedicated to a more general discussion and the preparation of a short report aiming to summarise the current state of the field and looking forward to future trends and developments in this new research field.

This meeting is sponsored by the European Science Foundation, for whose generous support we are truly grateful. We also wish to thank Staff at the University of Aarhus for their assistance in organizing this meeting, and in particular thank Dr N C Jones who has acted a local Secretary for this meeting, prepared the website and this Book of Abstracts and who assisted in many of the participants travel arrangements.

N J Mason
6/4/2002

Abstracts

(In alphabetical order of speaker)

Rubidium Condensates for Atomic Physics Studies

E. Arimondo
INFM, Dipartimento di Fisica, Università di Pisa,Via Buonarroti 2, I-56127 Pisa, Italy
(arimondo@df.unipi.it)

Different experiments with Bose-Einstein rubidium condensates are presented in order to evidence the impact of condensates as samples for the research in atomic physics and quantum optics. Measurements of the geometric forces acting on the condensate trapped into a time-orbiting-potential triaxial magnetic trap, the acceleration of the condensate within a one-dimensional optical lattice and finally the photoionization of the rubidium atoms composing the condensate are presented.

Metastable neon: Cold collisions and BEC

H.C.W. Beijerinck
Physics Department, Eindhoven University of Technology
(H.C.W.Beijerinck@tue.nl)

Based on a long-standing tradition of research on inelastic collisions, laser cooling and bright beams of metastable neon [8], we started a program in 1998 to investigate the feasibility of achieving Bose-Einstein Condensation in a dilute sample of trapped atoms [3]. The two crucial parameters are the effective suppression of ionization in a polarized gas and a sufficiently large scattering length to get evaporative cooling to work on a time scale corresponding to background dominated trap losses. The program involves both experimental and theoretical work on the suppression of Penning ionization [1,2], the role of heating collisions [4,5] and trapping/cooling of atoms and the loss processes involved [6]. The current status of the experiment is a population of 10^9 atoms in a compressed clover-leaf magnetic trap [7] with a residual gas dominated lifetime of 5 s. Ongoing experiments concern elastic collisions that repopulate the Boltzmann tail of the energy distribution after a cut-off with an rf-knife. A preliminary analysis indicates a large value of the scattering length, on the order of 200 a_0. The next step is to investigate the efficiency of model-based evaporative cooling cycles. The available diagnostics are absorption imaging, single atom/ion/uv-photon counting and fluorescence imaging/yield.

1) M.R. Doery et al., *Phys.Rev.A* **57**, 3603-3620 (1998)
2) M.R. Doery et al., *Phys.Rev.A* **58**, 3673-3682 (1998)
3) H.C.W. Beijerinck et al., *Phys.Rev.A* **61**, 023607 (2000)
4) H.C.W. Beijerinck, *Phys.Rev.A.* **61**, 033606 (2000)
5) H.C.W. Beijerinck, *Phys.Rev.A* **62**, 063614 (2000)
6) J. Schuster et al., *Phys.Rev.Lett.* **87**, 170404-1 (2001)
7) S.J.M. Kuppens et al., *Phys.Rev.A* **65**, 023410 (2002)
8) J.G.C. Tempelaars et al., *Eur.Phys.J. D*, 113-121 (2002)

Cold electrons, time delays and molecules

David Field
Institute of Physics and Astronomy, University of Aarhus, Ny Munkegade,
DK-8000 Aarhus C, Denmark
(dfield@ifa.au.dk)

Cold collisions involve particles whose wavelengths are much greater than the size of most molecules. Quantum scattering effects dominate the outcome of these collisions and raise a number of interesting conceptual questions, particularly relating to how they may be visualized. One question, very familiar to chemists, relates to how sticky are collisions between cold particles and how long they stay closely interacting. I will describe some of our recent experiments and attempt to put some physical clothes on virtual states and inelastic scattering involving cold electrons in collisions with CO_2 ,CS_2, benzene and naphthalene, using the concept of collision lifetimes. I will draw attention to the importance of cold electron processes in the interstellar medium. Theory suggests that cold collisions have a limiting stickiness lifetime, magnetically tuneable to a maximum value in cold atom collisions of $(8E)^{-1}$, where E is the collision energy. I hope that this may stimulate a discussion of how collision experiments using traps might be able to measure the time delay associated with cold atom encounters.

EIT enhanced optical nonlinearities in cold atoms

Andrew Greentree
Department of Physics and Astronomy, The Open University, Walton Hall, MK7 6AA
(a.d.greentree@open.ac.uk)

Electromagnetically Induced Transparency (EIT) promises to be an exciting new way of building non-linear optical media. EIT works by exploiting quantum interference in a three level atomic system to cancel the absorption of a weak probe whilst simultaneously enhancing its dispersion. In this way it is possible to realise a lossless material with extremely large non-linear refractive index. By exhibiting large nonlinearities without loss, it is possible (in theory at least) to realise single photon effects, opening up a new field of optics, quantum non-linear optics. Quantum non-linear optics extends classical non-linear optics into the quantum regime. We believe that the Magneto-Optical Trap is the ideal system in which to observe EIT. In this talk we will explain the fundamentals of EIT, advantages of the Magneto-Optical Trap over competing technologies and some of the recent experiments at the Open University including transient evolution of EIT and three photon resonances in a four level system.

Collisions, Condenstates and Optical Lattices

Paul S. Julienne
National Institute of Standards and Technology, 100 Bureau Drive, Stop 8423, Gaithersburg, Maryland, 20899-8423, USA
(paul.julienne@nist.gov)

The collisions and interactions of very cold atoms are very quantum mechanical in nature but can be precisely measured and characterized. We show that a coupled channels two-body scattering calculation with no adjustable parameters accounts for the measured rate of destruction of a Na Bose-Einstein condensate via one-color photoassociation of the v=135 vibrational level of the excited A singlet-sigma-u state [1]. The theory agrees well with the measured rate constant and the large level shift. The latter is due to coupling of the excited vibrational level to a ground state d-wave shape resonance. At the peak intensity of the experiment, the condensate destruction time is only 5 microseconds, but the rate constant is still about a factor of 6 below an upper bound predicted by many-body theory [2]. A recent experiment [3] also indicates that it will be possible to load condensates into tightly localized optical lattice nanotrapping cells loaded with one, two, or three individual atoms. We consider how collisions are modified when they occur in the tight confinement of an optical lattice cell.

1. C. McKenzie, J. Hecker Denschlag, H. Haeffner , A. Browaeys, Luis E. E. de Araujo, F. Fatemi, K. M. Jones, J. E. Simsarian, D. Cho, A. Simoni, E. Tiesinga, P. S. Julienne, K. Helmerson, P. D. Lett, S. L. Rolston, W. D. Phillips, *Phys. Rev. Lett.* **88**, 120403 (2002).

2. J. Javanainen and M. Mackie, *Phys. Rev Lett.* **88**, 090403 (2002).

3. M. Greiner, O. Mandel, T. Esslinger, T. Haensch, and I. Bloch, *Nature* **415**, 39 (2002).

Elastic and inelastic collisions in an ultra cold metastable helium gas

J. Léonard, F. Pereira Dos Santos, Erwan Jahier, Sylvain Schwartz, M. Leduc,
C. Cohen-Tannoudji.
Laboratoire Kastler Brossel, Département de Physique de l' École Normale Supérieure, 24 rue Lhomond, 75005 Paris, France.
(leonard@lkb.ens.fr)

I will give a talk about our recent investigations about elastic and inelastic collisions in a cold metastable helium ($^4He^*$) gas.

A helium beam in the 2^3S_1 metastable state is produced by an electronic discharge. It is then collimated, deflected and slowed down using the radiation pressure of a resonant laser beam locked on the 2^3S_1 - 2^3P_2 transition at 1.083 µm. 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. Two 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. Then, the cloud undergoes evaporative cooling and its phase space density increases up to the Bose-Einstein transition that occurs at a temperature of approximately 5µK. 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 ± 8 nm) and to give an upper boundary of the inelastic collision rate constants.

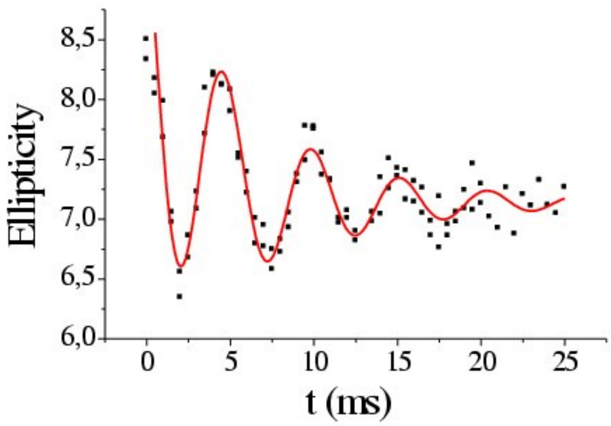

Figure 1: Quadrupolar m=0 oscillation of the cloud at 25 µK.

In the present stage of the experiment, we study the hydrodynamic regime (i.e. the mean free path between two elastic collisions is smaller than the size of the cloud in the weak axis of the trap) just above the transition. To perform this study we produce some collective excitations in the thermal cloud and we measure there frequency and damping which are related to the elastic collision rate. It appears that the maximum elastic collision rate we are able to produce is limited by inelastic losses and heating that they induce. We work at understanding the origin of this limit and at optimizing the route towards the highest possible elastic collision rates. In future work, we plan to study collective modes in the Bose-Einstein condensate in the presence of a hydrodynamic thermal cloud.

COLTRIMS with a MOT target: Fraunhofer diffraction of matter waves.

M. Machholm, M. van der Poel, C. V. Nielsen, M. Rybaltover, S.E.Nielsen, N. Andersen
Niels Bohr Institute, Blegdamsvej 17, DK-2100 Copenhagen, Denmark
(mette@machholm.com)

Due to small scattering angles (< 0.1 deg) in keV ion-atom collisions structures in angular resolved differential cross sections are completely obscured by the experimental resolution in conventional scattering experiments. However, the new experimental technique of cold target recoil-ion momentum spectroscopy (COLTRIMS) combined with a laser-cooled target makes the range of extremely small scattering angles accessible to study. We demonstrate this technique by measuring angle differential cross sections in Li^+ + Na -> Li + Na^+ electron transfer collisions in the 2.7 - 24 keV energy range. The present setup yields a momentum resolution of 0.12 a.u., an order of magnitude better angular resolution than previous measurements. This enables us to clearly resolve Fraunhofer type diffraction patterns in the differential cross sections. Parallel Atomic (AO) and Molecular Orbital (MO) semi-classical coupled-channel calculations of the Na(3s/3p) -> Li(2s/2p) state-to-state collision amplitudes have been performed, and quantum scattering amplitudes are derived by the eikonal method. The resulting angle-differential electron transfer cross sections and their diffraction patterns agree with the experimental results over most scattering angles in the energy range.

Formation of ultracold molecules via photoassociation of laser-cooled atoms: theoretical developments.

Françoise Masnou-Seeuws
Laboratoire Aimé Cotton, Bâtiment 505, Campus d'Orsay, 91405 Orsay, France

Whereas direct laser cooling of molecules is difficult, recent experiments have produced a large number of ultracold (T ≤ 100 μK) Cs_2 [1], K_2 [2], and Rb_2 [3] molecules by photoassociation of ultracold atoms in a magneto-optical trap. In a photoassociation reaction [4], two ground state alkali atoms A(*ns*) absorb a photon slightly red-detuned from the frequency of the resonance line, forming a molecule in a vibrational level *v* of an excited potential curve correlated to the first (*ns* + *np*) dissociation limit. **The vibrational motion in the asymptotic -C_3/R^3 potential often extends well beyond a few hundreds of Bohr radii or 0.01 μm**.

This excited molecule usually decays back into a pair of cold atoms. The **stabilization into a bound level of the ground state** requires a favourable Franck-Condon overlap between the excited- and ground- state vibrational wave functions. For the modelization of existing experiments, or the design of new schemes, our theoretical group has been working in four directions :

- Accurate vibrational wavefunctions, transition moments matrix elements, and predissociation lifetimes can be computed with a mapped Fourier Grid Method [5], where the grid step is adapted to the local de Broglie wavelength in order to reduce the size of the matrices.
- Using such methods, we have given a quantitative interpretation of experiments, and discussed the efficiency of various schemes to form cold molecules, including tunnelling effect [6] resonant coupling [7], and Feshbach resonances.
- The present accuracy of experiments is of the order of 10^{-3} cm^{-1} , well beyond the achievements of the best ab initio calculations. The uncertainty on short range potentials can be bypassed by use of asymptotic methods, such as Le Roy Bernstein formula [8] or generalized Lu Fano plots [9]. Such methods rely upon the analogy between a photoassociated molecule and a Rydberg atom. Parameters such as generalized quantum defects or reduced coupling are fitted to the photoassociation spectra [10].
- Finally, for the estimation of the formation rate of photoassociated molecules, we develop time-dependent methods [11]. The time-dependence of tunnelling effect has been analyzed recently.

Work in progress is focussing on the formation of molecules within a condensate.

[1] A. Fioretti, D. Comparat, A. Crubellier, O. Dulieu, F. Masnou-Seeuws, and P. Pillet, *Phys. Rev. Lett.* **80**, 4402 (1998).
[2] N. Nikolov, E. E. Eyler, X. T. Wang, J. Li, H. Wang, W. C. Stwalley, and P. Gould, *Phys. Rev. Lett.* **82**, 703 (1999).
[3] C. Gabbanini, A. Fioretti, A. Lucchesini, S. Gozzini, and M. Mazzoni, *Phys. Rev. Lett.* **84**, 2814 (2000).
[4] H. R. Thorsheim, J. Weiner and P. S. Julienne, *Phys. Rev. Lett.* **58**, 2420 (1987).
[5] V. Kokoouline, O. Dulieu, R. Kosloff, and F. Masnou-Seeuws, *J. Chem. Phys.* **110**, 9865 (1999).
[6] M. Vatasescu, O. Dulieu, C. Amiot, D. Comparat, C. Drag, V. Kokoouline, F. Masnou-Seeuws, and P. Pillet, *Phys. Rev. A* **61**, 044701 (2000)
[7] C. M. Dion, C. Drag, O. Dulieu, B. Laburthe Tolra, B., F. Masnou-Seeuws, and P. Pillet, *Phys. Rev. Lett.*, **86**, 2253--57
[8] R. J. LeRoy and R. B. Bernstein, *J. Chem. Phys.* **52**, 3869 (1970).
[9] V. Kokoouline, O. Dulieu, and F. Masnou-Seeuws, *Phys. Rev. A* **62** 022504 (2000)
V N Ostrovsky, V Kokoouline, E Luc-Koenig, and F Masnou-Seeuws *J. Phys. B* **34**, L27 (2001)
[10] V. Kokoouline, C. Drag, P. Pillet and F. Masnou-Seeuws, *Phys. Rev. A*, in press
[11] M. Vatasescu, O. Dulieu, R. Kosloff, and F. Masnou-Seeuws, *Phys. Rev. A* **63**, 033407 (2001).

External stimulation of atom traps

N J Mason
Department of Physics and Astronomy, University College London, Gower Street, London, WC1E 6BT, United kingdom
(nigel.mason@ucl.ac.uk)

To date the role of collisions in atom traps has been viewed mainly as detrimental- leading to trap loss - but recent experiments and new theoretical formalisms suggest that collisions between trapped atoms, between trapped atoms and external stimulation phenomena (e.g. photons) and between cold atoms and external surface media may lead to new physico-chemical phenomena that may, in turn, allow new exciting fields of atomic, molecular and optical and condensed matter physics to be developed.

A source of cold trapped atoms in a well defined quantum state provides an ideal target for leptonic (e.g. electron/positron) or photonic collisions. Preliminary experiments using electrons as a projectile have shown that trapped atoms may be used to measure total scattering cross sections and ionisation cross sections from both ground and excited atomic states with very high accuracy. Such measurements are required in many areas of applied science and technology but the accuracy of such measurements are currently limited by inherent problems in determining collisional geometries and the target and projectile number densities. Many of these problems are absent when the target is a well defined cold atom source, since absolute cross sections may be derived my measurement of only *ONE* number density and by the simple measurement of the ratio of trapped atom flux before and after electron irradiation. Hence cross sections may be measured with an accuracy of 1-2% for both ground state and excited state atoms, producing data that will provide authoritative data for testing modern theoretical formalisms of electron scattering from the heavier atomic targets. These experiments can, and should, now be developed to allow:

(i) electron collisions with unstable/radioactive nuclei (capable of being held in a trap e.g. Fr[17]),
(ii) using positrons to study antimatter - atom collisions,
(iii) using ultracold electrons (< 100 meV) to study electron cold atom collisions
(iv) to study electron interactions with cold *molecules* formed by photoassociation in a dense atom trap,
(v) to develop techniques for studying the role of ion/atom collisions in a trap, since the presence of ionic species might seed 'crystallization' of the neutral species in the trap and
(vi) to probe the effect of electron injection on the structure, cohesion and formation of cold atom clouds (including BECs) hence introducing the prospect of using condensed matter techniques i.e. electron diffraction to study cold atom physics.

Thus it is both timely and important to develop the techniques for leptonic scattering from cold atom sources. In this talk I will review the state of current experiments and discuss new experiments being develop to study the external stimulation of cold atom traps by leptonic collision partners.

Quantum-state control in non-dissipative optical lattices

David Meacher
Department of Physics and Astronomy, University College London, Gower Street, London, WC1E 6BT
(d.meacher@ucl.ac.uk)

In an optical lattice, the correlation between the spatial variations of ground-state light shifts and optical pumping rates in a spatially-varying light fields lead to the formation from an initially disordered gas of a structure, reminiscent of those found in crystalline materials in condensed matter. Whilst spontaneous emission is crucial to the localization of atoms within individual potential wells of the lattice, once the atoms are localized, the spontaneous emission can be suppressed to an arbitrary degree, by detuning the lattice field far from any atomic resonance. I describe how a scheme for resolved-sideband Raman-cooling can then be implemented in order to transfer all the atoms trapped in the lattice to its ground motional state, which is a minimum uncertainty state. I further discuss the techniques that can subsequently be employed to manipulate the quantum states of the atoms in the lattice.

Deceleration and trapping of neutral dipolar molecules

Gerard Meijer
FOM-Institute for Plasma Physics Rijnhuizen, P.O. Box 1207, 3430 BE Nieuwegein, The Netherlands
and
Dept. of Molecular and Laser Physics, University of Nijmegen, Toernooiveld, 6525 ED Nijmegen, The Netherlands
(gerardm@rijnh.nl)

It is now widely acknowledged that samples of cold molecules hold great promise for fundamental physics studies, and a variety of methods are currently being developed to produce such samples. In this presentation the operation principle of a linear decelerator in which time-varying inhomogeneous electric fields are applied to slow a gas pulse of dipolar molecules to arbitrarily low velocities (PRL 83 (1999) pg. 1558, PRL 84 (2000) pg. 5744, PRL 88 (2002) 133003) will be explained in detail. This method provides a fascinating novel tool for a large variety of molecular beam experiments. The so-called Stark decelerator has been used to generate slow packages of dipolar molecules for confinement in an electrostatic quadrupole trap (Nature 406 (2000) pg. 491), and for injection in a prototype storage ring for neutral molecules (Nature, 411 (2001) pg. 174).

Fermionic Lithium atoms in a Resonator-Enhanced Dipole Trap

Allard Mosk
University of Nijmegen. Dept. of Molecular and Laser Physics, Toernooiveld 1,
6525 ED Nijmegen, The Netherlands
(mosk@rijnh.nl)

We study the interactions in an ultracold trapped gas of fermionic lithium atoms, in a mixture of two Zeeman states. This system is a candidate for the observation of BCS-like pairing in atoms. Moreover, the interactions in this Fermi gas may be tuned, due to the prediction of a strong Feshbach resonance at 0.08 Tesla. We trap the atoms in a resonator-enhanced dipole trap, which exploits a factor 130 enhancement of the light intensity inside an optical resonator, to obtain a trap depth of more than 1 mK. The driving laser is a 2W Nd:Yag laser, with extremely good amplitude stability. We have studied exo-ergic interatomic collisions as well as interactions between the atoms and the trapping field. Although laser noise and photon scattering lead to heating of the sample, it can be shown that this is not too serious for e.g., evaporative cooling experiments. The main problem with evaporation of the fermionic Li is the small inter-state scattering length at low field, and the resulting low collision rate. At the moment, we are installing magnets to investigate the interactions near the Feshbach resonance. It is predicted that, using this resonance, the scattering length can be tuned from zero to large positive and negative values. It is even possible to make the scattering length exceed the confinement length of the trap.

Rotons in a Bose-Einstein Condenstate

Duncan O'Dell, Stefano Giovanazzi and Gershon Kurizki)
Sussex Centre for Optical and Atomic Physics, University of Sussex,
(D.H.J.Odell@sussex.ac.uk)

The effect of laser-induced dipole-dipole interactions upon a trapped gaseous Bose-Einstein condensate (BEC) are considered. The fully retarded dipole-dipole interaction can be very long-range (with terms decaying only as 1/r). This is in marked contrast to the usual very short range van der Waals type interactions found in the BECs which have been realised in the laboratory thus far. Furthermore, the magnitude and even functional form of the laser induced interactions can easily be controlled via laser intensity, polarisation, number and orientation of laser beams.

This talk concentrates upon two novel effects in these systems:

1. Electrostriction of a BEC.
The condensate is compressed by the dipole-dipole interactions and can even become self-bound.

2. Rotons in a gaseous BEC.
Dipole-dipole interactions also lead to more subtle effects by modifying the degree of atom-atom correlation. Quantum liquids, such as helium II, are far more strongly interacting than their dilute cousins the quantum gases, and correspondingly display correlation-induced behaviour such as the peculiar roton minimum in their excitation spectrum-a feature absent in conventional gaseous BECs due to the extreme weakness of their interactions. By enhancing the interactions in a gaseous BEC using dipole-dipole interactions one can introduce liquid-like properties such as a roton minimum and thus study the transition of a quantum gas into a quantum liquid.

Cold Collisions between atoms in near resonant optical lattices

Jyrki Piilo
Helsinki Institute of Physics, P.O. Box 64 (Gustaf Hallstromin katu 2),
FIN-00014 University of Helsinki, Finland
(jyrki.piilo@helsinki.fi)

We report Monte Carlo wave function simulation results for two colliding atoms in near-resonant optical lattices. The model describes simultaneously the two basic dynamical processes, the Sisyphus cooling of single atoms, and the light-induced inelastic collisions between them. We find that in a red-detuned lattice the hotter atoms in a thermal sample are selectively lost or heated by the collisions. Whereas in a blue-detuned lattice the efficient optical shielding of collisions is possible with suitably selected and realistic laser field parameters.

Formation, accumulation and trapping of cold molecules

Pierre Pillet
Laboratoire Aimé Cotton, CNRS II, Bât. 505, Campus d'Orsay, 91405 Orsay cedex, France.
(Pierre.pillet@lac.u-psud.fr)

Photoassociation of ultracold atoms followed by spontaneous emission opens a way for the achievement of samples of ultracold molecules. In a photoassociation process, two atoms absorb resonantly one photon to form a cold molecule in a ro-vibrational level on an electronically excited state. The efficiency of ultracold ground-state molecules depends of the branching ratio between bound-bound (formation of ultracold molecules) and bound-free (dissociation) transitions for the excited photoassociated molecules. Long-range states in particular below the dissociation limits 6s+6p of the cesium dimer can present interesting schemes with Condon points at intermediate distances, offering efficient channels for the formation of molecules in the ground state or in the lowest triplet state.

The complete processes (photoassociation and formation of cold molecules) will be completely analyzed. The experimental approaches will be presented. Different properties of the photoassociation mechanism will be described. The different schemes for the formation of cold molecules will be discussed. Measured temperatures of the obtained molecular cloud in the 10-200 μK range will be reported. The formation rates up to 0.2 cold molecule per second and per atom will be compared with those experimentally expected. The possibility for accumulating the so-formed cold molecules inside a trap, or for selecting them in a well-defined level in ground state will be discussed.

Structure of Trapped Degenerate Fermi Gases including s- and p-Wave Contact Interactions

Robert Roth
Clarendon Laboratory, University of Oxford, Parks Road, Oxford, OX1 3PU, UK
(robert.roth@physics.ox.ac.uk)

A short introductory part gives an overview of the experimental status in the field of ultracold trapped atomic Fermi gases and fermion-boson mixtures. With this background aspects of the theoretical treatment of dilute quantum gases are presented with emphasis on fermionic systems. The problem of correlations and the construction of a suitable effective interaction for a mean-field treatment of the many-body problem is addressed. Within the Thomas-Fermi approximation the energy density of trapped degenerate Fermi gases including effective s- and p-wave contact interactions is derived. This is the basis for the investigation of the structure and stability of degenerate single- and two-component Fermi gases. The collapse of the dilute gas due to attractive interactions and the separation of the components due to repulsive interactions are discussed in detail.

Phase Properties of Bose-Einstein Condensates

Klaus Sengstock
Institut fuer Laserphysik, Universitaet Hamburg, Jungiusstrasse 9, 20 355 Hamburg, Germany
(klaus.sengstock@physnet.uni-hamburg.de)

The realization of Bose-Einstein condensation (BEC) of weakly interacting atomic gases stimulates the exploration of properties of these systems like superfluidity, collective excitations and interactions within the systems. Of particular interest are the coherence properties of BEC, determined by finite temperature effects and collisions. An overview on the phase properties of condensates and their dependency on the dimension and geometry of the system will be given. Consequences for the fundamental aspects of BEC as well as for applications like atom lasers and atom optics will be discussed.

Studies of cold magnesium atoms

Jan W. Thomsen, F. Y. Loo, A. Brusch, C. V. Nielsen, D. N. Madsen, E. Arimondo, M. Allegrini and N. Andersen
Niels Bohr Institute, Oersted Laboratory, Universitetsparken 5, DK-2100 Copenhagen, Denmark
(jwt@fys.ku.dk)

Advances in sophisticated optical techniques have now made it possible to laser cool two-electron atoms such as magnesium. These systems, though, present a serious experimental challenge since their resonant wavelengths are typically in the UV range inaccessible to standard photon sources. Previous work has concentrated on symmetric alkali (Na, Rb, Cs) and rare gas (He, Ne, Kr, Xe) systems, all with easily accessible resonance transitions available from well-established light sources. All these systems, however, have inherent complications, namely the presence of fine or hyperfine structure splitting of atomic energy levels. This prevents quantitative experimental interpretation as well as detailed theoretical studies. Atoms with a simpler internal structure, such as magnesium, are therefore highly desirable. Emphasis is therefore put on the magnesium system, which offers an excellent system for benchmark testing of, e.g., quantum mechanical many body theories.

Recently we have constructed a major experimental setup for studies of cold two electron atoms at the Niels Bohr Institute in Copenhagen. Briefly, the cold atom setup consists of a magnesium atom source followed by a magneto-optical trap, MOT. The magnesium atoms are captured directly from the thermal magnesium beam. When the source is operated at 420ºC we capture about 10^6 Mg atoms in a volume of 0.1 mm^3. The MOT is a standard type with two small coils of diameter 25 mm and separated by 15 mm. The coil assembly can deliver a gradient up to 180 G/cm needed for efficient trapping of magnesium. The 285 nm light required for the MOT is produced by frequency doubling of a 570 nm dye ring laser in an external four mirror cavity using a BBO crystal. Our cavity is tuned to high output power for optimal atom trapping. The setup has the flexible possibility of being able to trap any of three stable magnesium isotopes ^{24}Mg (boson), ^{25}Mg (fermion) and ^{26}Mg (boson) independently. This offers the possibility of adding complexity to the system since ^{25}Mg has a nuclear spin of 5/2 and thus possesses hyperfine structure in contrast to ^{24}Mg and ^{26}Mg which have zero nuclear spin.

Under typical trapping conditions the average atom density will be of the order of 10^{10} atoms/cm^3 and the minimum temperature 2 mK set by the so-called Doppler limit. This density is suitable for observing quantum mechanical two body effects between trapped magnesium atoms. Cold atoms interacting are usually revealed in form of energetic atoms leaving the trap. By studying the MOT fluorescence after the magnesium beam is cut off, we have seen evidence of cold atoms interacting.

Cooling of Internal and External Degrees of Freedom in Heteronuclear Molecular Ions

Ivan S. Vogelius, Michael Drewsen, and Lars B. Madsen
Institute of Physics and Astronomy, University of Aarhus, Ny Munkegade, DK-8000 Aarhus C, Denmark
(ivansv@ifa.au.dk)

The translational motion of molecular ions can be sympathetically cooled in an ion trap by Coulomb interaction with laser-cooled atomic ions. However, the internal degrees of freedom are not affected by the sympathetic cooling and within seconds they will be in equilibrium with the blackbody radiation, leaving the molecular ions in the vibrational ground state, but distributed over rotational levels. We present general schemes for cooling of these rotational degrees of freedom of trapped, diatomic, heteronuclear molecular ions. The schemes are based on optical pumping into excited vibrational states and subsequent spontaneous decay into an effective ``dark state''. Blackbody radiation induces transitions between rotational levels, and thus transfers population from higher-lying rotational states to the states that are pumped. More than 95% of the population can be transferred to the rotational ground state, corresponding to an internal temperature of a few degrees Kelvin. The schemes are effective for a large number of ions.

Interaction processes in a mixture of ultracold gases

Matthias Weidemüller
Laser Cooling Group, Max-Planck-Institut für Kernphysik. D-69029 Heidelberg, Germany
(m.weidemueller@mpi-hd.mpg.de)

We simultaneously trap ultra-cold lithium and caesium atoms and study the interaction processes between the gases. We present detailed investigations of light-induced exoergic Li-Cs collisions performed in a two-species magneto-optical trap. Spin-changing collisions and exchange of thermal energy are observed by simultaneously confining both species in an optical dipole trap formed by the focus of a CO_2 laser. The Cs gas, which is optically cooled to 20 μK, efficiently decreases the temperature of the initially hotter Li gas through sympathetic cooling. Besides thermalization, we observe evaporation of Li purely through elastic Cs-Li collisions accompanied by cooling of the Cs gas (sympathetic evaporation).

Simultaneous trapping of Na atoms in a two-species MOT and their interactions

L. Windholz, V. Wippel, C. Binder
Institute of Experimental Physics, Technical University of Graz, Petersgasse 16, A-8010 Graz, Austria
(windholz@iep.tu-graz.ac.at)

Simultaneous trapping of different atomic species is of interest in order to study interaction cross-sections, interaction potentials and the formation of heteronuclear molecules.

Na and ^{7}Li atoms have been cooled and trapped in a magneto-optical trap (MOT) simultaneously, captured out of vapor produced by dispensers or out of weakly collimated atomic beams from furnaces. As light sources we use two dye lasers, actively stabilized to the D_2-lines of Na and Li. The cooling and re-pumping frequencies are produced by acousto- or electro- modulators. Both the yellow and red laser beams are overlapped by dichroitic mirrors. The position of each clod of trapped atoms can independently be chosen within a small interval, so both clouds can be overlapped easily in the center of the trap. The colouds are examined using a CCD-camera and a photo diode equipped with appropriate filters. The fluorescence intensity during loading the trap with Li was observed in absence and in presence of the could of Na atoms. When the Na cloud is present, additional losses are caused by collisions between the different atom species, leading to a lower equilibrium number of captured Li atoms.

The loading curves for N_{Li}, the number of Li atoms, in presence of Na have been fitted using a numerical integration of

$$\frac{dN_{\mathrm{Li}}}{dt} = L - \gamma_0 N_{\mathrm{Li}} - 2\beta' \frac{(n_{0,\mathrm{Li}} n_{0,\mathrm{Na}} N_{\mathrm{Li}} N_{0,\mathrm{Na}})}{\sqrt{((n_{0,\mathrm{Na}} N_{\mathrm{Li}})^{2/3} + (n_{0,\mathrm{Li}} N_{0,\mathrm{Na}})^{2/3})^3}}$$

where L is the loading rate, γ_0 the loss rate without Na, β' the cross-section of Na on Li, $n_{0,\mathrm{Li}}$, $n_{0,\mathrm{Na}}$ the densities without the other cloud, $N_{0,\mathrm{Na}}$ the number of Na atoms. All these values except β' are known from measurements with only one element. As a preliminary result, we have obtained an interaction cross-section of $\beta' = 10^{-11}$ cm^3/s ±15%. Compared to Rb-Cs [1] β' is one order of magnitude smaller for Li-Na.

These investigations are preliminary steps on the way towards the production of cold heteronuclear molecules LiNa by using the technique of photoassociation.

Acknowledgements

The project is supported by Fonds Zur Förderung der Wissenschaftlichen Forschung, project numbers P 11877 and 14645.