Progress towards a Molecular BEC of Lithium Dimers

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Quantum degenerate fermions

Lithium $^6$Li:
- Innsbruck (R. Grimm)
- MIT (W. Ketterle)
- Paris (C. Salomon)
- Rice (R. G. Hulet)
- Duke (J.E. Thomas)

Potassium $^{40}$K:
- Boulder (D. Jin)
- Florence (M. Inguscio)

Work in progress: Strontium, Ytterbium, Chromium
Aims

• To produce a BEC of composite bosons (molecules)
  • Load $^6$Li atoms into the optical dipole trap
  • Evaporatively cool the atoms
  • Feshbach creation of molecules

• Work with theorists on understanding nature of dissociated atoms from MBEC and in general this complex system
**Bosons versus Fermions**

**Bosons**
- Integral spin
- Conform to Bose-Einstein statistics
- Do not obey Pauli-exclusion Principle, i.e., bosons can collapse into the same quantum state

**Fermions**
- Half integral spin
- Conform to Fermi-Dirac statistics
- Obey Pauli-exclusion principle, i.e., two atoms cannot occupy the same quantum state
Fermion + fermion = boson

- Feshbach resonances are used to manipulate interactions in atomic gases
- Ability to resonantly control the scattering properties of the gas
- Fermion $\rightarrow$ composite boson gives long MBEC lifetimes (> 10 s)
- $^{40}$K, bosonic Cs, Rb, Na, fermionic Li

A Feshbach resonance occurs when a bound state for one spin combination has identical energy with the unbound state of another spin combination.
Making Molecules

three atoms

three-body process

atom

molecule

$^6\text{Li}_2$ molecules formed by 3-body recombination in tightly confining optical trap

(D. Petrov PRA 67, 010703 (2003))
Melting point: 180°C, At 400°C vapour pressure is 5x10^-5 mbar

Isotope: 
- $^6\text{Li}$
- $^7\text{Li}$

Natural Abundance: 
- 7.5%
- 92.5%

Nuclear Spin: 
- 1
- 3/2

Lithium corrosive to glass

50% - 50% mixture of $^6\text{Li}$ atoms in the lowest two ground states (not magnetically trappable). Avoids any two body decay channels
Load $^6$Li atoms into a MOT from a slowed atomic beam

Transfer atoms to a far-off-resonant optical dipole trap (FORT, Yb:YAG, 25 W, $\lambda$: 1030nm)

Evaporatively cool by reducing FORT depth

Evaporation is performed at a magnetic field strength that enhances 3-body recombination (molecules) - *Feshbach resonance at $\sim 834$ G

Continue evaporation to remove atoms, and condense remaining molecules
To Achieve a MBEC ......

- Laser system
- Vacuum system
- Optical dipole trap
• Saturation spectroscopy of lithium vapour produced in a vapour cell provides the frequency reference for the experiment.
• We lock our lasers using frequency modulation spectroscopy-modulation directly applied to the laser diode current
Vacuum System

- Oven: 400 °C
- Atom velocity from oven: 1500 m/s
- $\sigma$-Zeeman Slower
- Max B field: 600 G
- Capture velocity: 50 m/s
- Pressure: $1 \times 10^{-11}$ Torr

**Slowing Zeeman beam**
Parameters for FORT:

- Wavelength: 1030nm
- Power: 20 W
- Waist: 40 µm
- Trap Depth: 930 µK
- Single dipole trap
  - Single with retro reflection
  - Crossed dipole trap
- $\omega = 2 \times (4.5, 4.5, 6.4)$ kHz

precise control of laser power
20 W $\rightarrow$ 20mW

forced evaporation
Results……So far

• Slowed Atomic Beam
• Magneto Optical Trap
• EIT and EIA spectra
Slowed Atomic Beam

How did we probe the velocity distribution?

- Probing the velocity distribution with an external cavity laser under a small angle of incidence.

Zeeman Slowing Beam

- Peaks from vertical beam
- Peaks from 30° angle beam

Can slow down lower velocities at higher fields

Detuning

- Zeeman: 820 MHz
- Repumper: (820-228) MHz

Frequency of probe laser is swept over 1-2 GHz
$^{6}$Li Magneto Optical Trap

- Atom Number: $2 \times 10^8$ Atoms
- Lifetime: 35s
- Loading Time: 15secs
- Flux: $2 \times 10^7$ At/s
- Oven Temp: 400°C
- Pressure: $1 \times 10^{-11}$ T
Future Work

• To study the dissociation of the condensate molecules into correlated atom pairs
  • MBEC created from fermionic atoms – dissociation of MBEC

  *Kheruntsyan & Drummond*
  *Phys. Rev. A, 66, 031602*

• Future prospects for the BCS-BEC crossover regime for our parameters

• Collective Excitations
  • investigate interactions
  • probe finite temperature effects

• Experiments on fermionic atoms in optical lattices
Proposed Outline

- Slowed lithium beam
- $^6\text{Li}$ MOT
  - Atoms loaded in FORT – May 2006
  - Evaporative cooling – Oct 2006
  - Feshbach creation of molecules – Dec 2006
  - Molecular BEC – early 2007
Go Raibh Mile Maith Agat