Quantum Degenerate Mixtures of Lithium and Ytterbium

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UW INT Workshop, 16th May 2011
Mixtures

Spin Mixtures
Distinguishability for technical (cooling) and scientific (strong interactions & polarized gases)

Isotopic mixtures
Further ease of cooling
Different statistics
(slightly) heteronuclear

Elemental Mixtures
Large differences in mass, electronic structure.
Heteronuclear – dipolar molecules
Species selective techniques
Li and Yb have different electronic structure and very different mass.
A little about $^6$Li

Established cooling methods:

Red laser cooling line at 671nm

Evaporative cooling to degeneracy 2-spin states at a convenient B in an optical trap

Sympathetic cooling by a boson ($^7$Li, $^{23}$Na, $^{87}$Rb) in a magnetic trap

Ground State of $^6$Li

Magnetic Feshbach Resonance (MFR)

Molecular BEC/Fermi Superfluid/ Universal Physics/ BEC-BCS crossover near Feshbach Resonance at 834G.
A little about Yb

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A little more about Yb

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Many isotopes cooled to degeneracy (Kyoto)

Atomic clock on $^1S_0 \rightarrow ^3P_0$ (NIST, others)

Heavy – useful for precision measurements
eg. e-EDM search in $^3P_2$

Yb fermions in optical lattice
Quantum simulation, quantum computation

When mixed with alkali:
Good collisions only - spin-zero ground state
Additional species selectivity with B field gradient

Possibility of paramagnetic polar molecules
The Li-Yb combination

Ground States: Collisionally stable mixture expected. However very small thermalization factor (~21 collisions per particle for thermalization).

Mass Ratio = 29, B-F and F-F combos available
  new collisional regime (>13.6)
  new many-body regime (highly mismatched Cooper pairs?)

Tunable interactions
  Magnetic Feshbach resonances – available?
  Optical Feshbach resonances – usable?

Microscopic/Impurity probe of the $^6$Li superfluid

Other similar mixtures:
Rb+Yb (Dusseldorf, NIST), Li+Yb (Kyoto), Rb+Sr (Innsbruck)
The Li-Yb combination

A paramagnetic polar molecule with electronic degree of freedom

Dipolar physics
Quantum simulation of lattice spin models
Quantum computing
Sensitive test of fundamental symmetries (e-EDM)

Ground state molecule production by ultracold atom association in Jin/Ye group (KRb), Weidemuller (LiCs), DeMille (RbCs), Nagerl (Cs₂),...
**Feshbach resonance in LiYb?**

Only doublet-sigma ground state potential for alkali+spin-singlet collisions. No “usual” MFR.

Weak MFRs may exist [Hutson and co-workers, PRL 105, 153201 (2010)]

Ab-initio Li-Yb potentials from Zhang et al. JCP 133, 044306 (2010).
Optical Feshbach Resonance

Optically connect free particles with an excited molecular state. Initial proposal by Shlyapnikov and others [PRL 77, 2913 (1996)].

[First observation in Grimm group Theis et al, PRL 93, 123001 (2004)]

[Grimm, Takahashi, Killian, Jun Ye]

Internuclear Distance (R)

Photoassociation Resonance

Further theory work by Bohn, Julienne, co-workers
More applicable with narrow optical transitions
Co-trapping of Li and Yb

**AGENDA**
- Cool and trap Li and Yb
- Study interacting mixture
- Induce controlled interactions
- Form molecules

**Ultrahigh Vacuum (UHV < 10^{-10} Torr)**
Yb MOT and double MOT

Sequential Loading
The 2 MOTs are optimized at different parameters of magnetic field gradient and also exhibit inelastic interactions.
Optical Dipole Trap

Shallow angle (20 degrees) crossed beam dipole trap 1064nm, up to 25 Watts
Optical Dipole Trap

Shallow angle (20 degrees) crossed beam dipole trap 1064nm, up to 25 Watts
Co-trapping of Lithium and Ytterbium

1064nm optical trapping potentials for Li and Yb. $\omega_{Li}/\omega_{Yb} = 8$

Controlling the relative numbers
Ground State behavior of Li-Yb mixture

It’s stable!

Extract $|a|=(13 \pm 3) a_0$ ($\sim 0.7$nm, kind of small)
Sympathetic Cooling to below $T_F$

Small interspecies scattering length, but light Li provides high relative speed.

$T/T_F \sim 0.7$

$T/T_{BEC} \sim 4$

Ivanov et al, PRL 106, 153201 (2011)
Bose-Einstein condensation of $^{174}$Yb in a 1.06\( \mu \text{m} \) trap

A straightforward method to create Yb BECs in 1064nm potential. Quasi-pure BECs with up to 50,000 atoms possible

Recent technical improvements: improved laser cooling, tighter optical confinement.
Simultaneous Quantum Degeneracy in alkali + spin-zero system

$N_{Yb} \sim 25,000$
$T \sim 120nK$
8ms TOF

$N_{Li} \sim 15,000$
$T_{Li}/T_F < 0.3$
0.7ms TOF

Recent similar results in Takahashi/Doyle collaboration
Implications for other Li-Yb combinations

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What Next?

Search for Magnetic Feshbach Resonances

Decay of Li atoms near 834 G MFR

Atom loss spectroscopy

Li MFR in the presence of Yb.
Collisions with distinguishable 3rd component (heavy, boson/fermion)
Impurity/microscopic probe of $^6$Li superfluid
What Next?

Photoassociation Spectroscopy

Provides information on excited potential
Key step towards LiYb molecule
Key step towards Optical Feshbach Resonance
UW Ultracold Atoms Team

Grad Students: Will Dowd, Anders Hansen, Alan Jamison, Alex Khramov, Ben Plotkin-Swing
Undergrad: Ben Schwyn
Post-doc: Vlad Ivanov (now at UW Madison)

$$$ - NSF, Sloan Foundation, UW RRF, NIST