Cold Atom Experiments (I) [Jin]

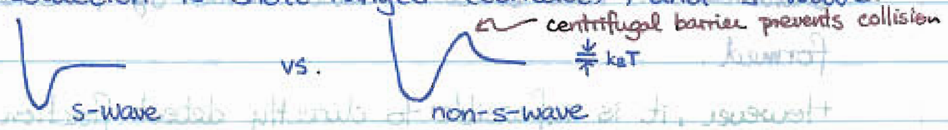
- atom vs electrons

	atom	electrons	
$n =$	10^{13}	10^{23}	cm^{-3}
$N =$	10^{5}	∞	
$m =$	7×10^{-26}	9×10^{-31}	kg
$T_F =$	10^{-6}	10^{5}	K
$T/T_F =$	0.05	<0.001	

- Atom trap necessarily has inhomogenous density
  - ▲ typical size of traps ~ μm.
  - ▲ Cyclindrical traps are more common than spherical ones.

- Important properties of ultracold (~100nK) gas:
  - ▲ meta-stable (ground state is solid)
    - ⟹ want the gas to be dilute
    - ▶ Experiment time span ~ minutes, hence generally no problem
  - ▲ Spin degree frozen out
    - $k_B T \ll E_{Zeeman}$

  - ▲ Interaction is short-ranged (contact), and s-wave.



  - ▲ By Pauli exclusion, two spin-polarized fermions can't interact

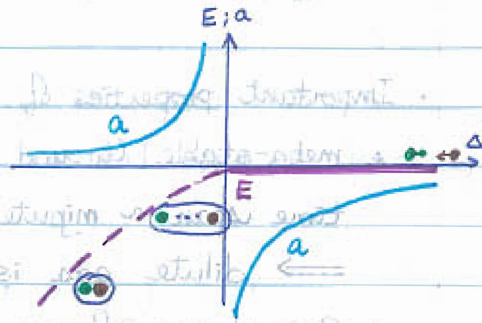
- Gas cooling: (1°) laser cooling & trapping (~μK)
  (2°) magnetic trapping & evaporating cooling
  (3°) optical trapping & evaporating cooling } (~nK)
  - In (3°) laser is far detuned to prevent photon scattering
  - In evaporative cooling atoms of different species needed, for equilbratio
  - (3°) is preferred to (2°) since it works for all spin state, and additi
    B-field can tune interaction, etc.

- Time-of-flight
  - ▲ Suddenly turn off the trap, let the gas free fall & expand
  - ▲ Take photon absorption image.

- Cold fermionic atoms : ^{40}K, ^{6}Li, ^{173}Yb, $^{3}He^*$ (i.e. metastable)
  - ▲ Alkali atoms prefer since it makes laser cooling easier.

- Extracting temperature
  - ▲ Fit tail of expanded gas to Fermi-Dirac distribution with two parameters μ, T. (T_F known from density, etc.)
  - ▲ Equilibration time ~ 1 s.

- Magnetic-field Feshbach resonance



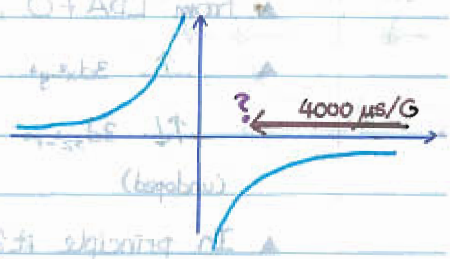
  - ▲ Measurement obtained by tuning density and take spectroscopy, and looking at the energy shift between high/low density
  - ▲ The molecule no longer absorb light tuned to the atomic transition. This allows measurement of fraction of molecule formed.

    However, it is infeasible to directly detect fraction of molecule by tuning to molecular resonance energy, since molecule breaks upon absorbing the photon, hence only 1 photon per molecule and hence weak signal.

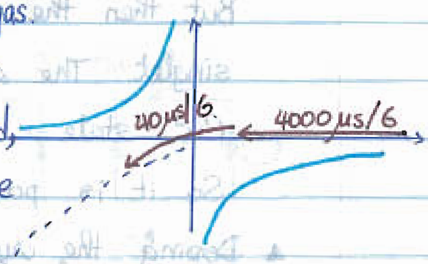
    Since this is a crossover, when ΔB is very close to 0, the loose molecule still absorbs the original light freq.
  - ▲ The lifetime is long, but becomes shorter when far away from resonance.

- Real-time tuning of interaction strength. (from BCS to BEC side)
  - ▲ Fast ($2\,\mu s/G$) $\Longrightarrow$ system remains a Fermi sea.
  - ▲ Slow ($40\,\mu s/G$) $\Longrightarrow$ system form molecules, but with some despersion.
  - ▲ Slower ($4000\,\mu s/G$) $\Longrightarrow$ condensation of molecules.

- Fermi Condensate ?



  - ▲ If TOF measurement is made on the attractive (BCS) side, as the gas expand it returns to non-interacting limit and we see simply the result of free Fermi gas.



  - ▲ Instead make a fast ramp and go into the BEC side. If <u>condensate</u> is obseved, then there must be some condensation before the ramp.
  - ▲ The TOF image on the BEC side shows the momentum distribution of fermion pair, NOT individual atoms.