A new trap loading mechanism for Hydrogen

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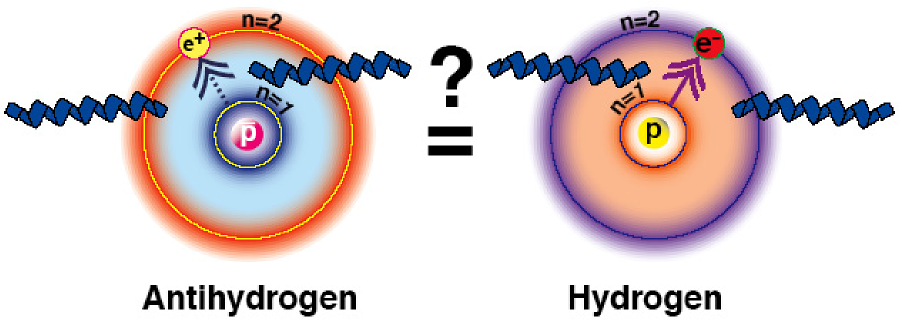
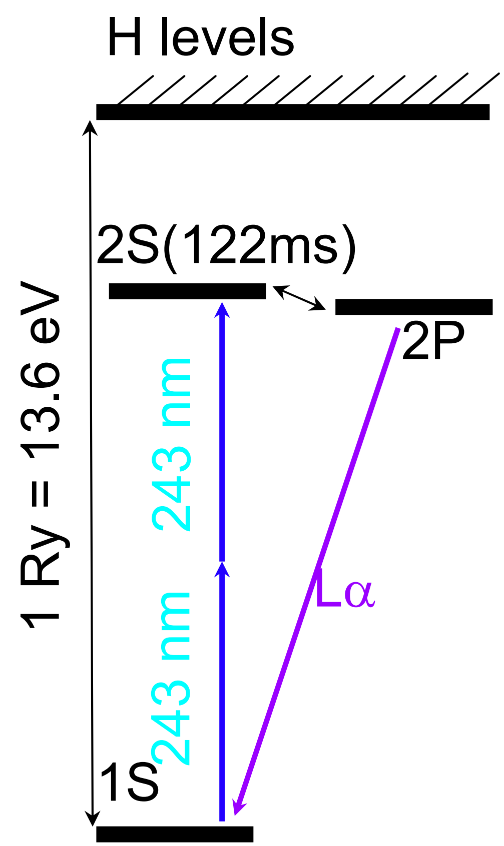
Motivations to build a new H-trap

- Have a reference for the ALPHA project to test CPT performing the spectroscopy of anti-H and comparing it to hydrogen





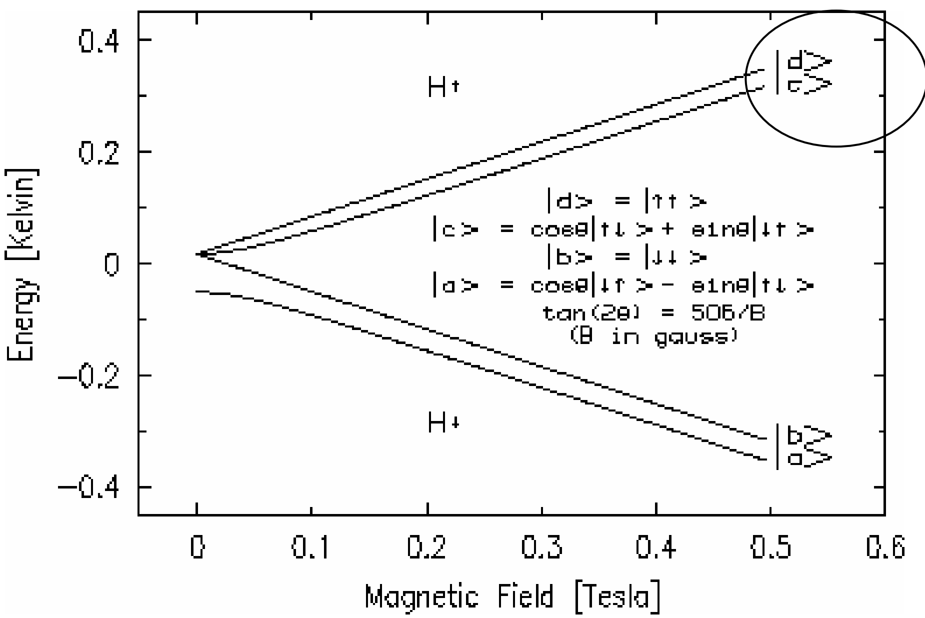
•Further analysis of the MIT 1S-2S experiment shows that the trap holds the promise of higher precision measurements than a cryogenic beam (ultimate precision that could be of 1 part in 10^{18})

•Possibility of trapping H-Deuterium simultaneously
→ Precise measurement of H isotope shift

•Future measurement of H Hyperfine structure (?)

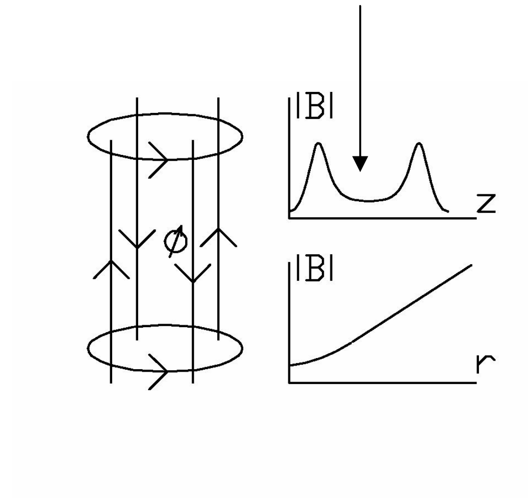
Principle of magnetic trapping

$$\vec{E} = -\vec{\mu}\cdot\vec{B}$$



Low field seekers

Trappable states

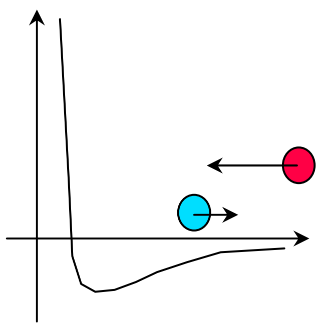


$$\mu \cdot B \gtrsim k_B \cdot T$$

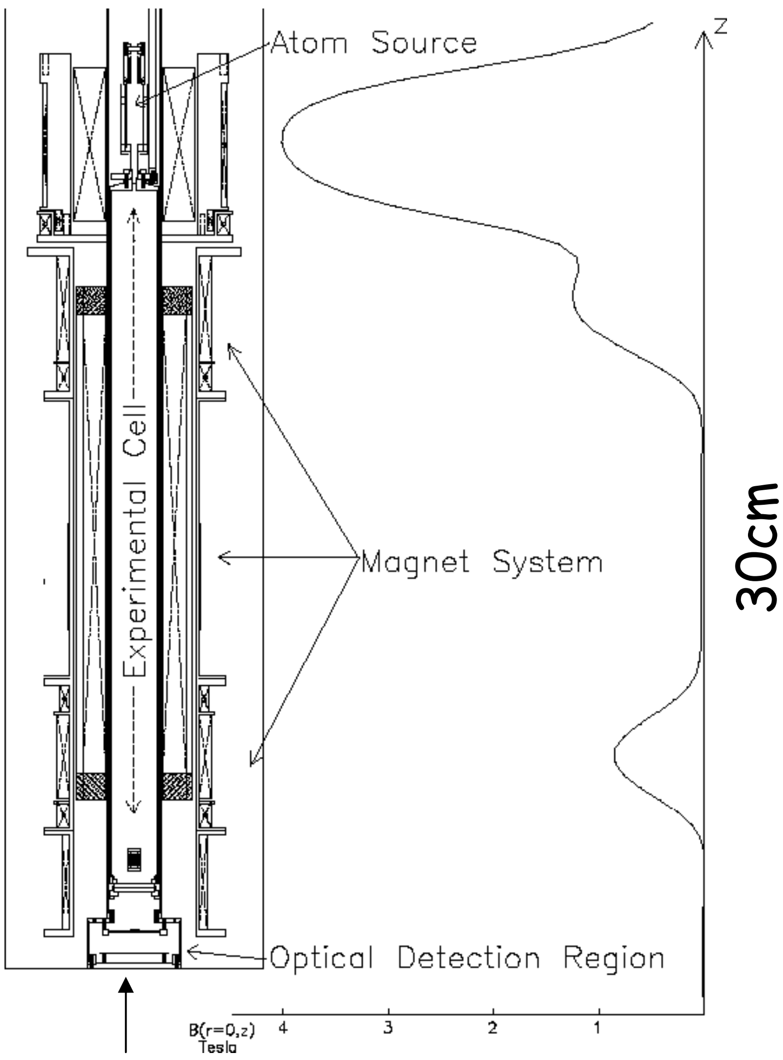
The trap depth for 1T is 0.67 K ⟹ Need to cool the atoms

Loading mechanism based on H onto LHe

The existing H traps have so far relied on the very particular property of the low binding energy of H onto superfluid helium.

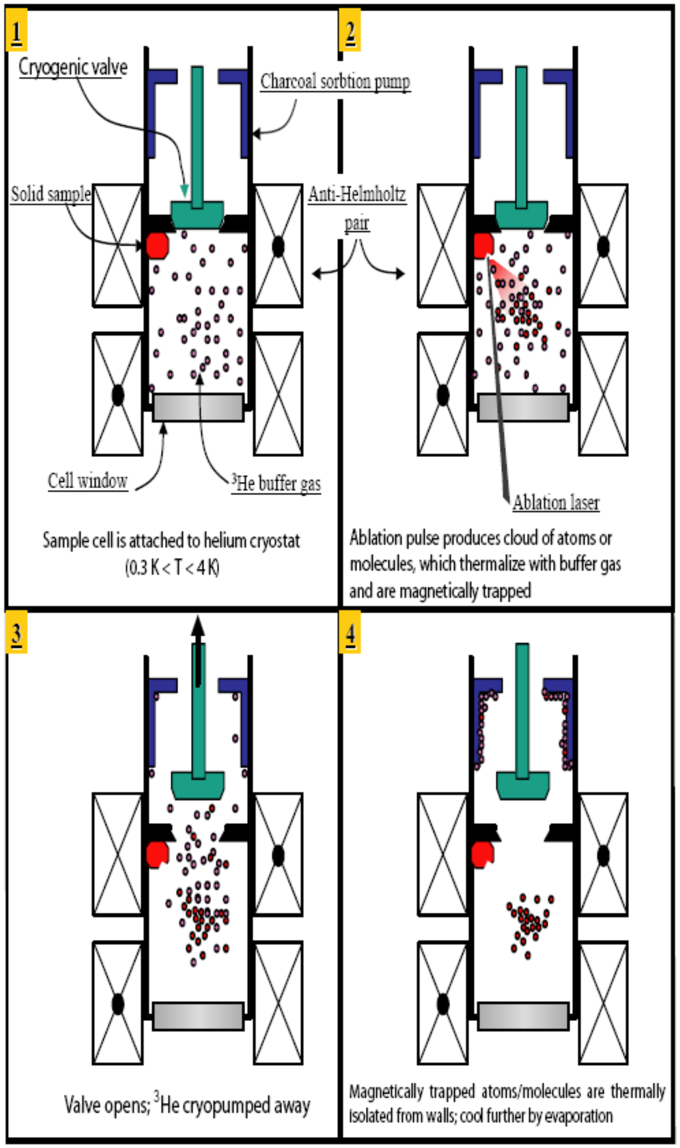


However, the H traps at Amsterdam, Harvard, and MIT that used a ^3He-^4He dilution refrigerator were so complex that they have been discontinued.



Very small solid angle for Lyman alpha photons detection $<10^{-5}$

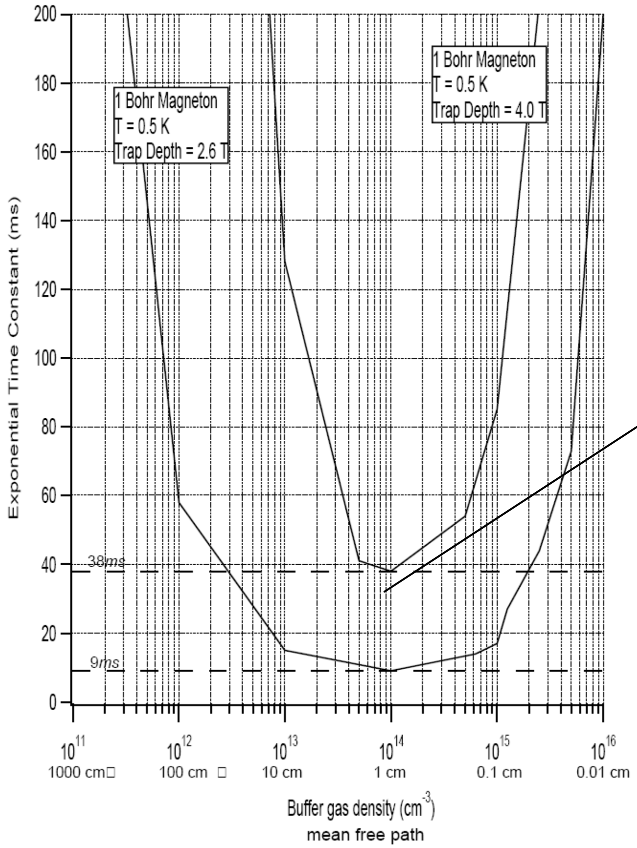
Buffer gas technique -1



Very successful, 17 atoms and 4 molecules have been trapped. Potentially more species…

State ${}^{2S+1}L_J$	μ (in μ_B)	Element
${}^2S_{1/2}$	1.001	H, Li, Na, K, Cu, Rb, Ag, Cs, Au, Fr
${}^4S_{3/2}$	3.003	N, P, As, Sb, Bi
${}^6S_{5/2}$	5.006	Mn, Re, Te
${}^7S_3$	6.007	Mo, Cr
${}^8S_{7/2}$	7.007	Eu
${}^2P_{3/2}$	2.001	F, Cl, Br, I, At
${}^3P_2$	3.002	O, S, Se, Te, Po
${}^6D_{1/2}$	1.669	Nb
${}^2D_{3/2}$	1.199	Sc, Y, La, Lu, Ac
${}^3D_3$	4.002	Pt
${}^9D_2$	5.303	Gd
${}^5D_4$	6.005	Fe, Os
${}^3F_2$	1.332	Ti, Zr, Hf
${}^2F_{7/2}$	3.994	Tm
${}^3F_4$	5.002	Ni
${}^4F_{9/2}$	6.003	Co, Rh, Ir
${}^5F_5$	7.005	Ru
${}^1G_4$	3.782	Ce
${}^6H_{5/2}$	3.782	Pm
${}^3H_6$	6.983	Er
${}^6H_{15/2}$	9.938	Tb
${}^5I_4$	2.413	Nd
${}^4I_{9/2}$	3.290	Pr
${}^4I_{15/2}$	8.964	Ho
${}^5I_8$	9.933	Dy

Buffer gas technique -2



- Need to start at high density for good thermalisation.
- To have thermal isolation one must have a density of the buffer gas smaller than 10^{10}-10^{11} cm^{-3}
- One has to pass to a region were the lifetime is at a minima ("the death valley")
- This would suggest that the buffer gas should be removed as fast as possible However, if one tries to do it in less than about <40 ms all trapped atoms are removed from the drag force of the "wind" from the buffer gas atoms ⇒ losses…

Desorbing of Helium from the film on the wall creates a background gas

⇓

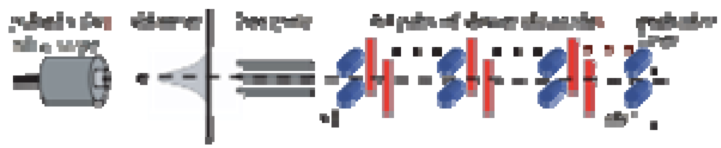
For the moment no thermal isolation has been achieved for 1 bohr magneton species (Best result was ^{7}Li , n=10^{9} that was cooled to 80mK)

Other methods for cooling atoms

laser cooling:

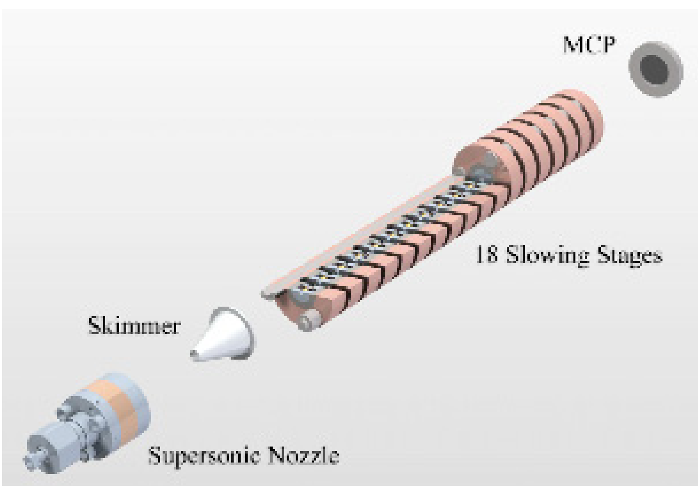
nobelprize.org

Stark Deceleration

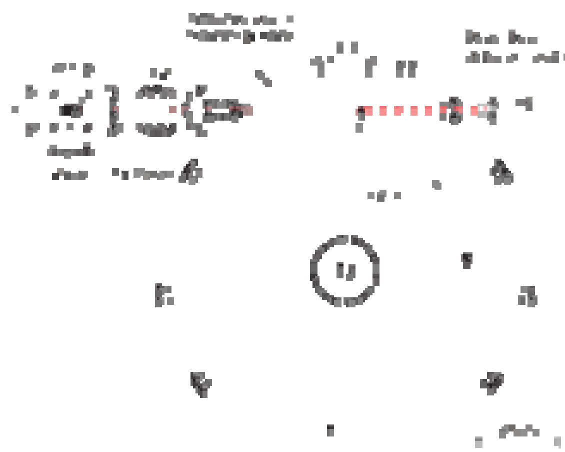


E.Hudson et al.

M.Raizen's "coilgun"



Raizen's "Paddle"



Proposal for a new Trap-loading technique

RAPID COMMUNICA

PHYSICAL REVIEW A 76, 061401(R) (2007)

Spectroscopy of low-energy atoms released from a solid noble-gas matrix: Proposal for a trap-loading technique

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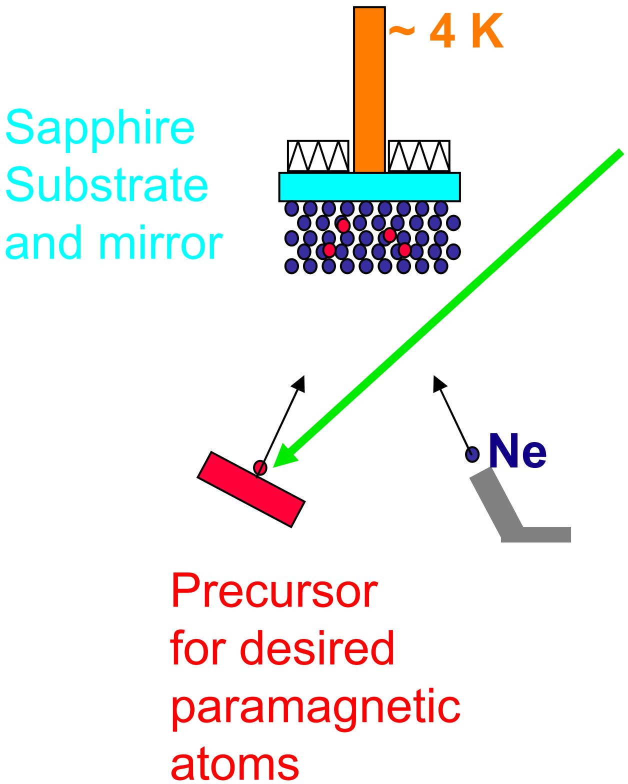
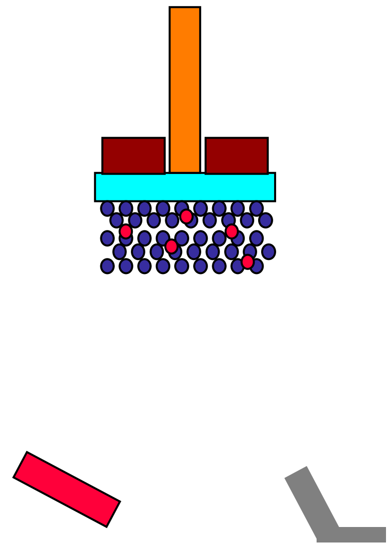
We have studied the velocity distribution of chromium atoms released from a solid neon matrix at cryogenic temperatures via Doppler spectroscopy. The Ne matrix is grown by directing a small flux of gas onto a cold substrate, while Cr atoms are simultaneously implanted by laser ablation, with the resultant plume directed toward the growing matrix. The atoms are then released by a heat pulse. We have observed neutral Cr atoms at temperatures around 13 K with densities close to 10^{12} cm^{-3}. The released atoms have a large initial drift velocity, explained by simple kinetic theory arguments, due to the light species' drag force. The scheme could be adapted to produce cryogenic beams of atoms, molecules, and possibly ions, for collisional studies and spectroscopy. However, our main motivation was the construction of a hydrogen trap, and here we discuss the prospects and problems of using this technique for this purpose.

Production of cold (~15 K) Atoms

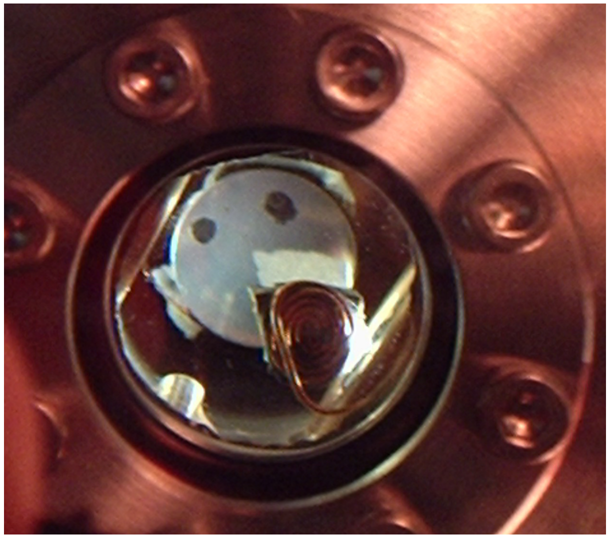
Deposition Process



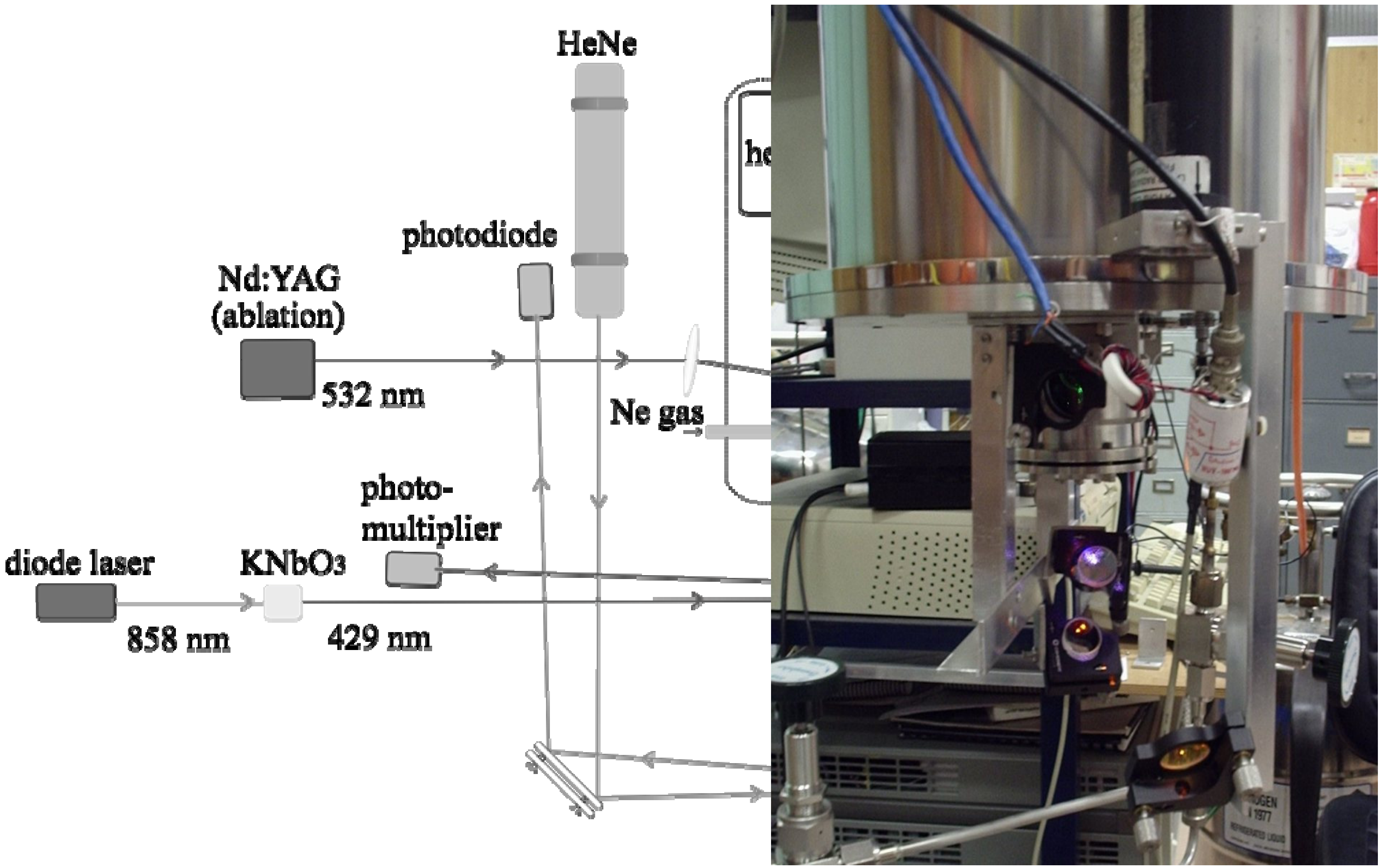
Releasing Process



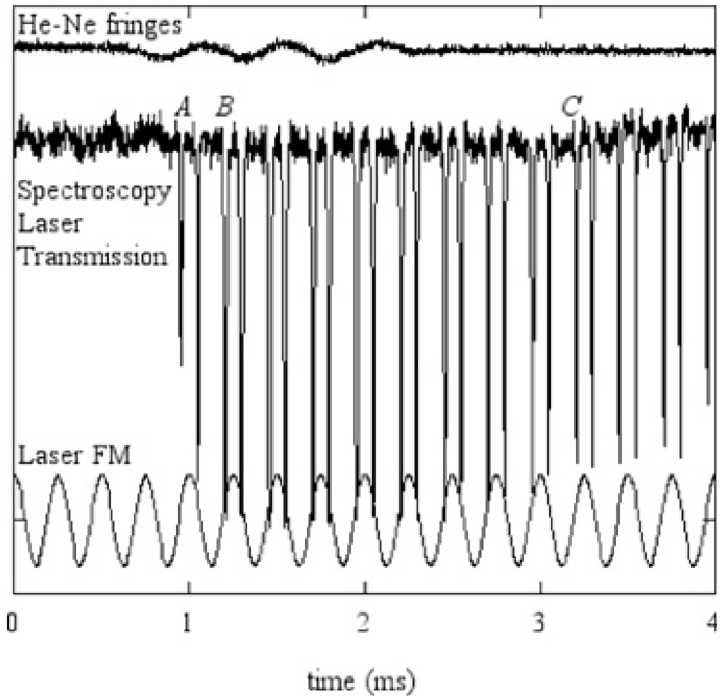
To study this process Doppler spectroscopy was performed on the $^7S \rightarrow {}^7P_0$ transition of the ^{52}Cr



Experimental Setup



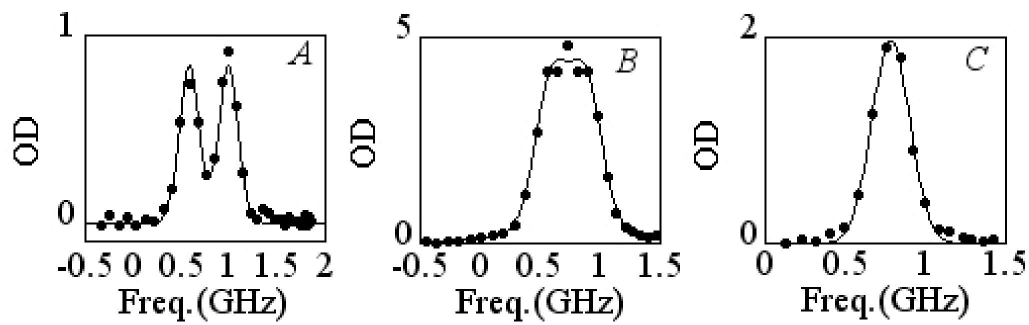
Analysis of Cr Atoms spectroscopy

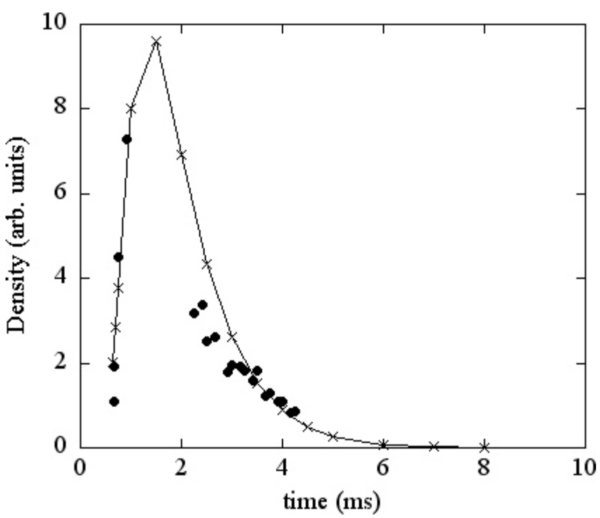


A shows a drift velocity, causing a line-doubling due to the Doppler effect by the laser being retroreflected on the mirror.

B shows the doublet structure—characteristic of freshly released atoms—together with a more thermal, Maxwellian line.

C shows a good fit to a Maxwell-Boltzmann distribution. The thermalization of the sample, and the consequent disappearance of the drift velocity, is due to Ne atoms reflecting off the cell walls and redistributing its kinetic energy.





Results with Cr Atoms

Flux of atoms at saturated vapor pressure reaching the surface:

$$\Phi_{\mathrm{MB}}(v_x) = m v_x (kT)^{-1} e^{-m v_x^2/(2kT)} \text{ with } v_x > 0, \longrightarrow \phi = AP/\sqrt{2\pi m k T_s},$$

Energy distribution:

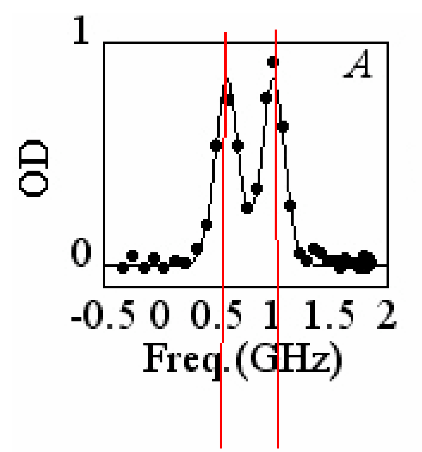
- $<E_x> = 1kT_s$ $<E_{Tot}> = 2kT_s = 1/2(m v_{cm}^2) + 3/2kT'$
- $T' = T_s(8-\pi)/6$

Doppler broadening: $\delta v_{DS} = v_{cm}/\lambda = \sqrt{[(\pi k T_s/2m)]}/\lambda$, $\Delta v_\sigma = \sqrt{[(\pi k T'/2m)]}/\lambda$

- $\delta v_{DS}(Ne) = \sqrt{[3\pi/(8-\pi)]}\, \Delta v_\sigma(Ne)$

Assuming $v_{cm}(Cr) = v_{cm}(Ne)$ and $T'(Cr) = T'(Ne)$ one has:

- $\delta v_{DS}(Cr) = \sqrt{[3\pi m_{Ne}/(8-\pi) m_{Cr}]}\, \Delta v_\sigma(Cr)$
- $\delta v_{DS}(Cr) = 2{,}24\, \Delta v_\sigma(Cr)$



Our results: $\delta v_{DS}(Cr) = 0{,}216$ GHz, $\Delta v_\sigma(Cr) = 0{,}106$ GHz

$\delta v_{DS}(Cr)/\Delta v_\sigma(Cr) = 2{,}2$

$T' = 13$ K, Density = 10^{12} cm^{-3}

→ support to the model above with the Cr being entrained in the Ne

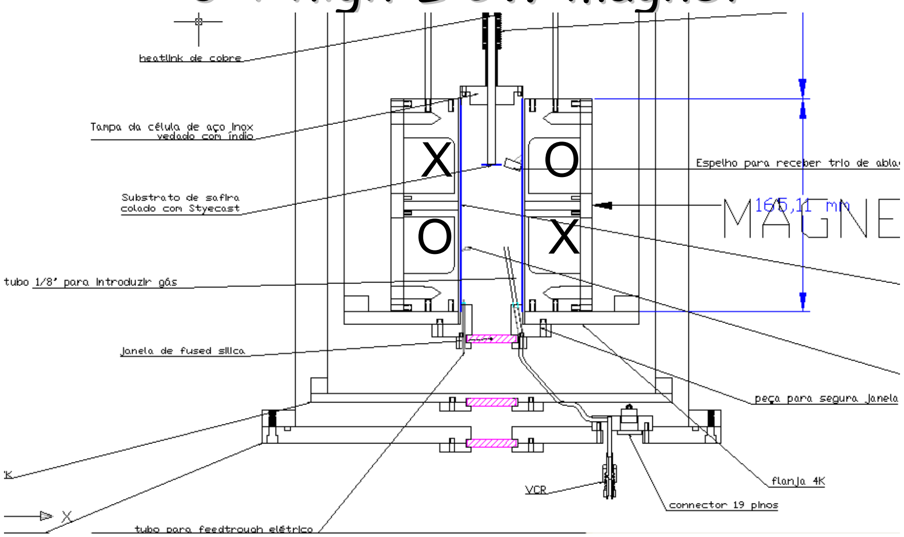
Next step - magnetic trapping

<u>Proposal for a trap loading</u>: magnetically capture the low-energy fraction of the released paramagnetic atoms while the host Ne atoms stick to the walls (or in the charcoal).

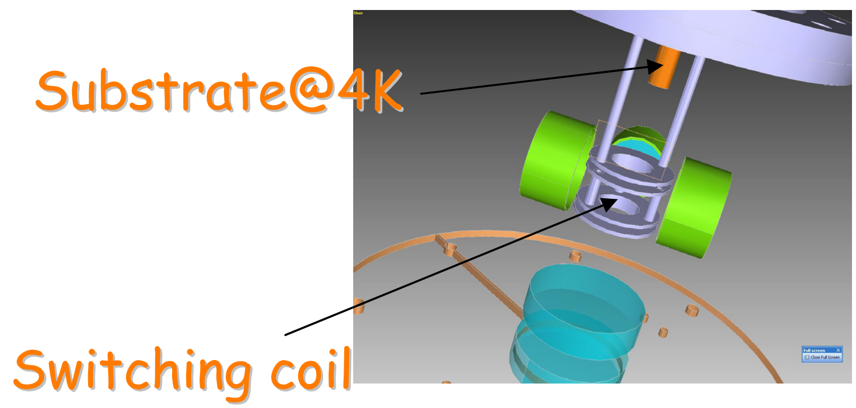
Simultaneous trapping of H and Li, due to their large mutual elastic cross section (1500 times higher than H-H), for later evaporative cooling

For light species ($m_s < M_{Ne}$), the drift velocity does not significantly affect their kinetic energy.

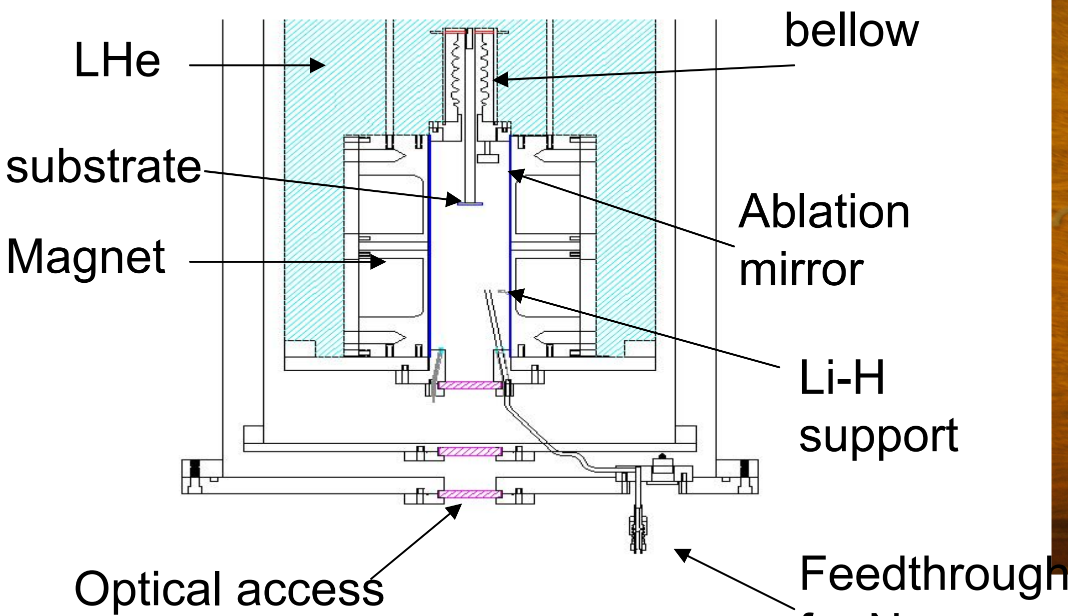
3 T high-L CW magnet

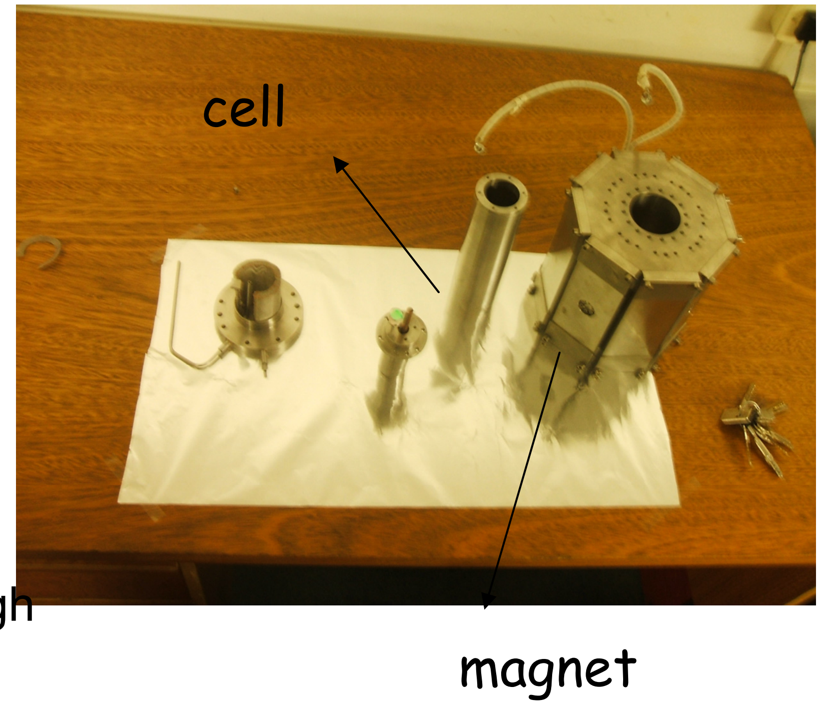


1 T miniature low-L switching magnet



The 3T DC trap

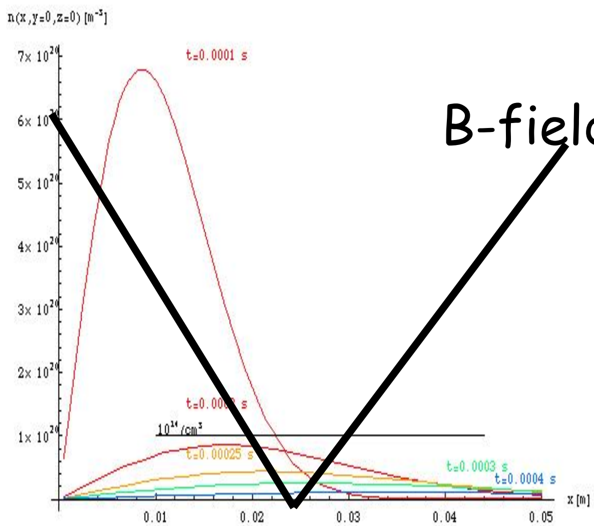


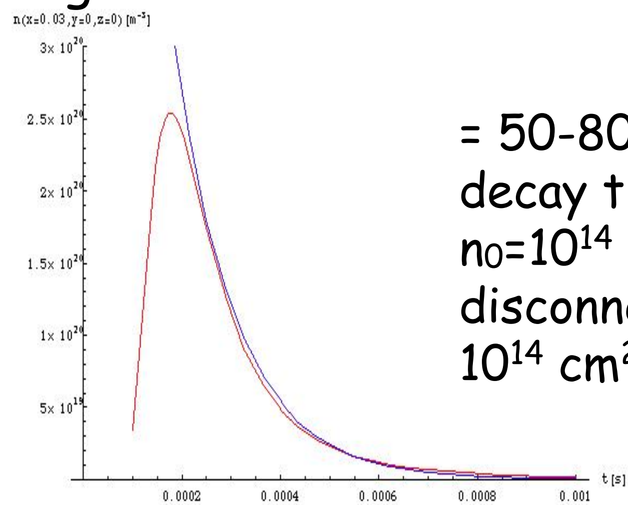


All parts have been produced, we are waiting for the laser to perform spectroscopy to arrive to check that we can produce ^{7}Li by laser ablation of Li-H at room temperature before starting the assembling.

Mechanism for trapping

The drag of the host atoms would provide the dissipation mechanism necessary for trapping prevent the acceleration of the atoms from the magnetic field





= 50-80 μs density decay time

$n_0=10^{14}$ at/cm^3

disconnect at

10^{14} cm^2

n , y=0, z=0, t … t1=0 … S … m … kTs … ã … -m … 2kTs … m … 2p kT' … ã … -m … 2kT' … - t1

The density of the Neon gas can be tuned with the duration of the heat pulse applied, the distance between the substrate and the trap center to maximize the trapping efficiency

Detection & Expected number of trapped atoms

Detection of ^{7}Li atoms:

- Transition $2^2S_{1/2} \rightarrow 2^2P_{3/2}$ @ 671nm
- Issue: when B-field on, spin relaxation of our paramagnetic atoms inside the host matrix? Adiabatic rapid passage?

Expected number of trapped atoms

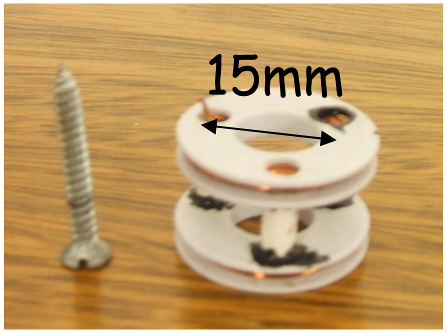
- In matrix isolation spectroscopy dilution of atoms up 10^{-3}
- For an initial number Ne= 4×10^{15} atoms => H, ^{7}Li =4×10^{12} atoms.
- For the 3 T magnet: 3% of thermal H sample at 15 K is expected to be trapped, which corresponds to a n_H = $3{,}0 \times 10^{9} cm^{-3}$

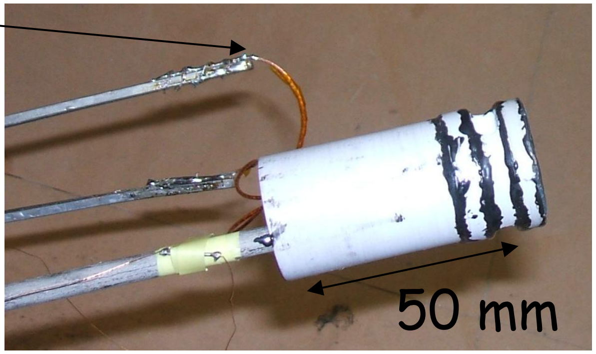
Evaporative cooling:

- Having the ^{7}Li atoms trapped togheter increase the efficiency of evaporative cooling (the cross section is about 10^{-12}).
- For the density we expect to trap the time scale of the process should be of the order of few seconds.
- After cooling, the Li could be expelled from a trap by radiofrequency or laser induced spin flip.

The 1T switched trap

Miniature magnet, anti-helmholtz configuration, 15 mm diameter,
9 windings of supercon wire, low inductance 1 μH





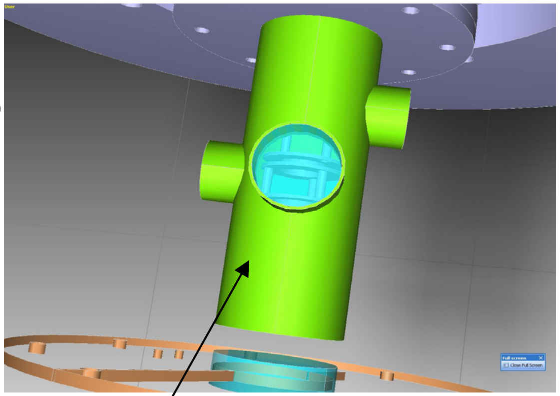
Advantages:

• Much more optical access compared to MIT experiment the detection efficiency for the Lyman alpha photons would be 4 orders of magnitude higher

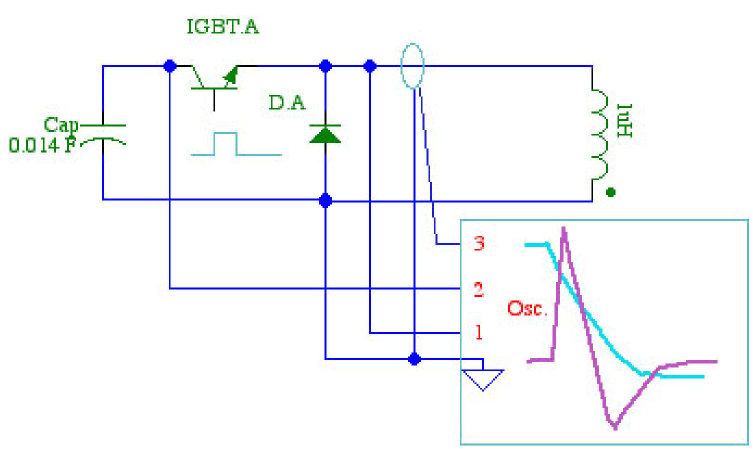
•Inexpensive, no need for big power supply

•It can be switched on when the atoms are in the center of the trap (no problem with spin relaxation).

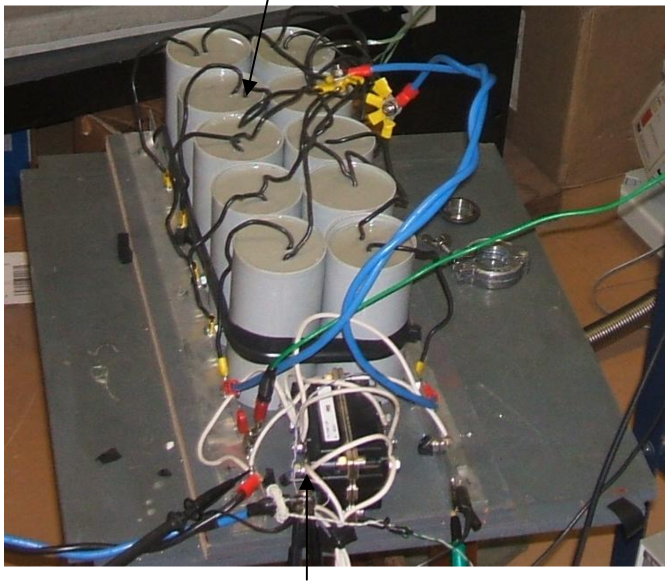
Disadvantage lower trap depth



The 1T switching test- Set up



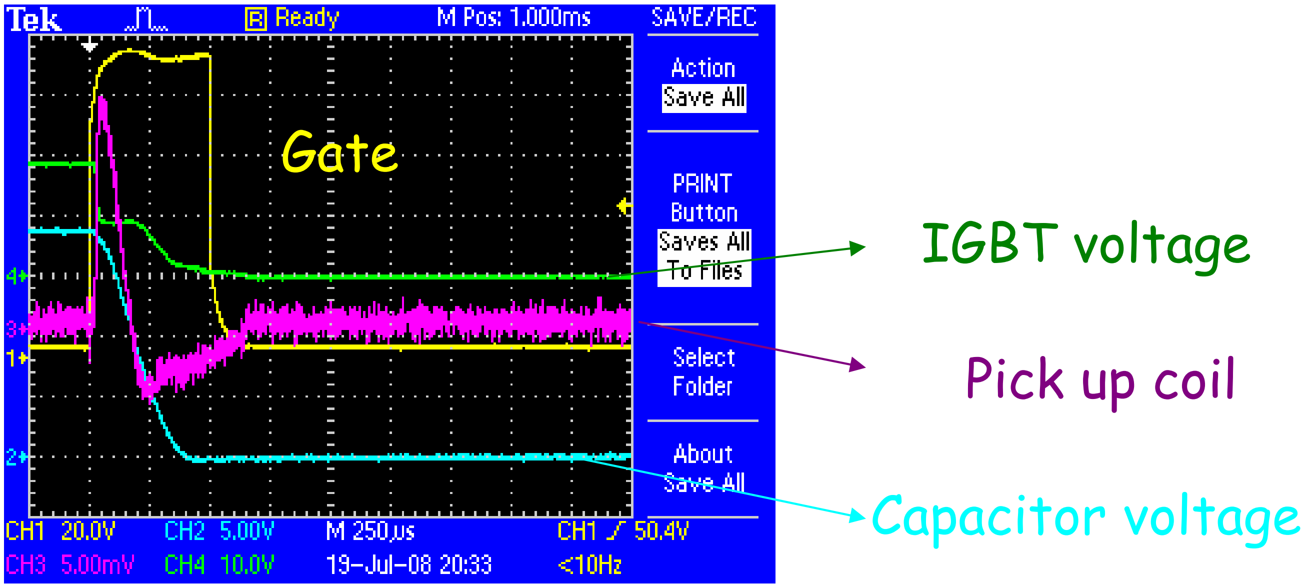
10 Capacitors = 14 mF



IGBT

Dewar filled with LHe

The 1T switching test - preliminary results



Switching test: <u>1000 Amperes in 100 µs</u>

⇒ For our 9 windings coil of 1.5 cm diameter corresponds to approximately 0.6 T

⇒ Next step increase the current until a quench occurs.

Limit should be 1700A which corresponds to a trap depth of about 1 T since this is the critical current at 2T at the wire

The 1T switching trap

Expected number of trapped atoms

•For an initial number Ne= $4x10^{15}$ atoms H, ^{7}Li =$4x10^{12}$ atoms.

•For the 1 T magnet: 0.3% of thermal H sample at 15 K is expected to be trapped, which corresponds to a n_H = $3,0x10^{8}cm^{-3}$

Evaporative cooling:

For the density we expect to trap the time scale of the process should be of the order of tens of seconds.

Car battery => effective energy storage device. For example, a lead-acid car battery of 50 Ah capacity can supply 50 A of current, at 13.8 V for an hour. Therefore the stored energy of a car battery is more than 2 MJ!

The maximum current, allowed for a battery usually rated as 10 C, i.e. ten times the ampere-hour value. Putting more batteries In parallel we expect to be able keep 1000 A for few minutes.

Summary and Outlook

The production of a new kind of source for cold atoms (@15 K) based on a matrix isolation was presented.

A 3T magnetic trap was constructed to test the idea of magnetic trapping Li and H atoms released from the Ne matrix
=> Results are expected in next months

The preliminary results of the switching 1T trap test are encouraging.

This technique could open the possibilities for a very simple trap for light molecules => precision measurements and quantum information