固体NMRで検知する表面近傍の偏極気体原子のスピン流

Solid NMR Detection of Spin Current of Optically Polarized Atomic Vapor

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Motivation

Spin Transfer

Photon → Optical pumping (atomic gas) → Alkali-metal → (spin capacitor) Noble-gas

Source of angular momentum

Loss: atomic collision, wall relaxation

Alkali-metal → **Diffusion spin current**: Flow of longitudinal spin angular momentum $\langle S_z \rangle$ $\langle I_z \rangle$

Alkali-metal → **Spin injection through a surface**: Injection of polarized electron; Nuclear dipole interaction (direct or indirect) → Solid

Hyper-polarization

^{13}C : 2D or confined electrons

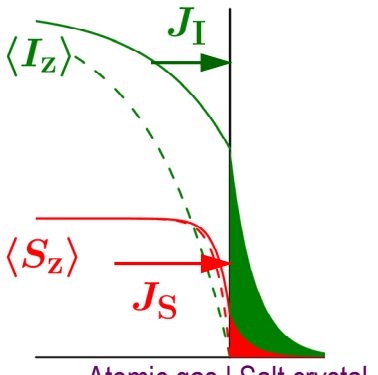
^{29}Si : Amorphous, Crystal …

$^{6}Li^{+}$, $^{7}Li^{+}$, $^{133}Cs^{+}$: Ionic crystal

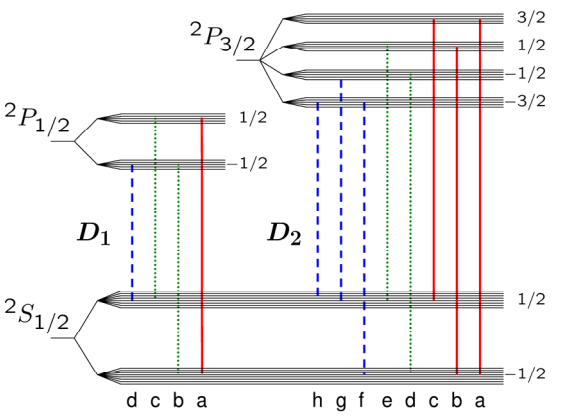
Improvement of boundary condition

Change of atomic state in gas phase

Spin diffusion



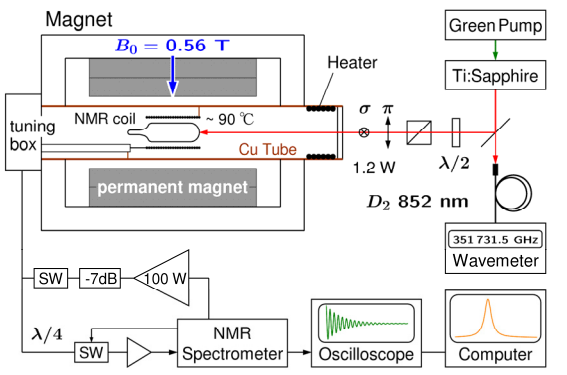
Energy Level



Energy levels of Cs atoms at high field. Zeeman splitting of electron state $|Sm_S\rangle$ ($|Jm_J\rangle$) is larger than the hyperfine splitting. Projection m_S (m_J) is indicated by half integers. Eight nuclear spin levels $|I=7/2\ m_I\rangle$ lies in each electronic manifold. Vertical lines show the transitions of the D_1 (D_2) line in the order of resonance frequency from right to left, correspondingly named from a to d (a to h) . Each transition can be induced by the pump of any polarization due to the mixing between the direct product states $|Sm_S\rangle|Im_I\rangle$ or $|Jm_J\rangle|Im_I\rangle$. The strongest absorption among them is indicated by the vertical lines as red (σ+), green (π), and blue (σ–).

See absorption cross section at the bottom.

Experimental Setup



Metal Knight shift
Atom Hyperfine structure
→ NMR frequencies far from that of solid nuclei

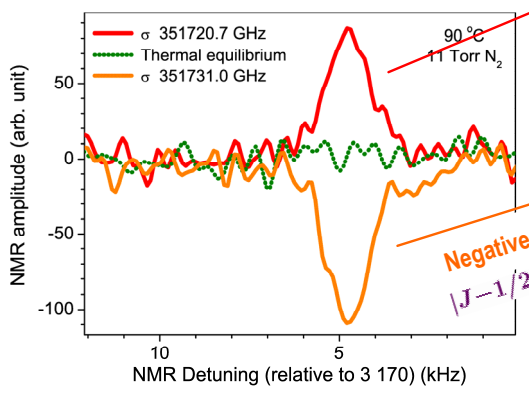
CsH salt was solely NMR detected.

Pump light from continuous-wave Ti:Sapphire laser was routed into a permanent magnet. The linearly-polarized light by the polarization beam-splitter and half-wave (λ/2) plate uniformly illuminated a cylindrical cell. The oven temperature was regulated @ 90 ℃ by a resistive heater and PID controller. Free-induction decay (FID) was observed by a solenoid coil sensing alkali-salts on the side wall of glass cell. Trace of NMR line was Fourier transform of the transient signal.

Enhancement of Cs Nuclear Spin Polarization

One of double peaks comes from $|J{-}3/2\rangle|Im_I\rangle \leftarrow |S{-}1/2\rangle|Im_I\rangle$ by σ– pump. J_I is positive because of the quenching of excited state and the mixing of ground state, $|S\ {-}1/2\rangle|Im_I\rangle + \epsilon|S\ 1/2\rangle|Im_I - 1\rangle$ The quenching by N_2 molecules destroys <Sz> while retaining <Iz> of the excited state. Since the mixing at excited state is smaller than ground state, <Iz> increases by ϵ^2 for a single cycle of depopulation and repopulation pumping.

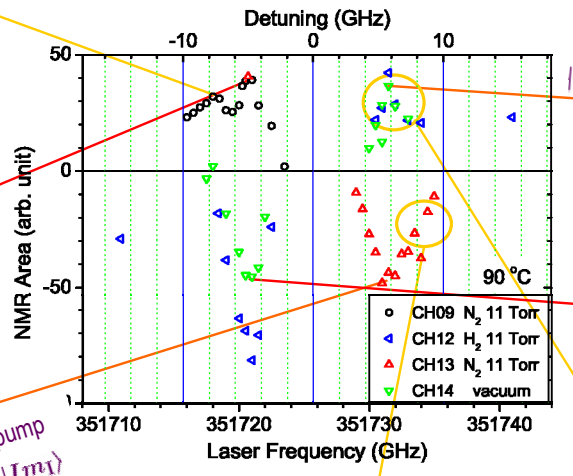
The other peak corresponds to J_I by σ+ pump through the transition $|J\ 1/2\rangle|Im_I + 1\rangle \leftarrow |S\ 1/2\rangle|Im_I\rangle$



NMR enhancement of CsH salt by *D2* pumping with σ light at 0.56 T. Thermal signal was too small to be detected. Each spectrum was a Fourier transform after averaging 70-shots of FIDs. RF pulses were applied with a tipping angle of π/3 every 100 s. CsH crystallites and the excess Cs metal were contained in CH13 cell filled with N_2 gas of 11 Torr.

NMR enhancement spectra of CsH salt

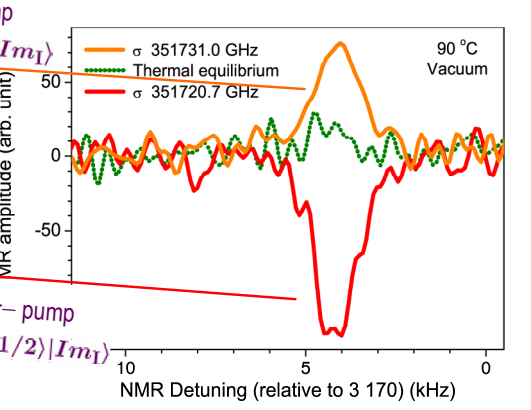
Each point presents the area of NMR trace



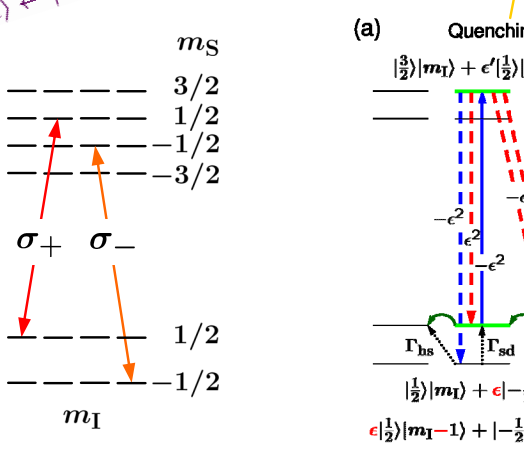
Positive peak by σ+ pump $|J\ 3/2\rangle|Im_I\rangle \leftrightarrow |S\ 1/2\rangle|Im_I\rangle$

Negative peak by σ– pump $|J{-}3/2\rangle|Im_I\rangle \leftrightarrow |S{-}1/2\rangle|Im_I\rangle$

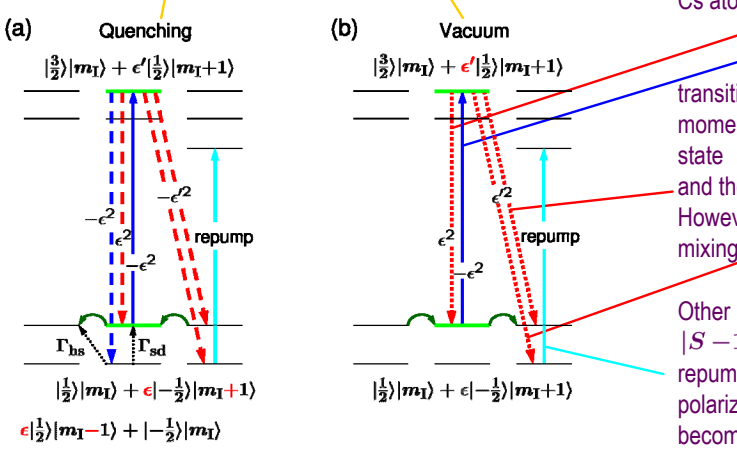
Negative peak is due to J_I by σ– pump $|J{-}1/2\rangle|Im_I - 1\rangle \leftarrow |S{-}1/2\rangle|Im_I\rangle$



NMR enhancement of CsH salt by *D2* pumping with σ light at 0.56 T. The spin polarization reversed sign by CH14 cell with no buffer gas.



Nuclear spin polarization of Cs atoms has the same helicity as pump light for these transitions.



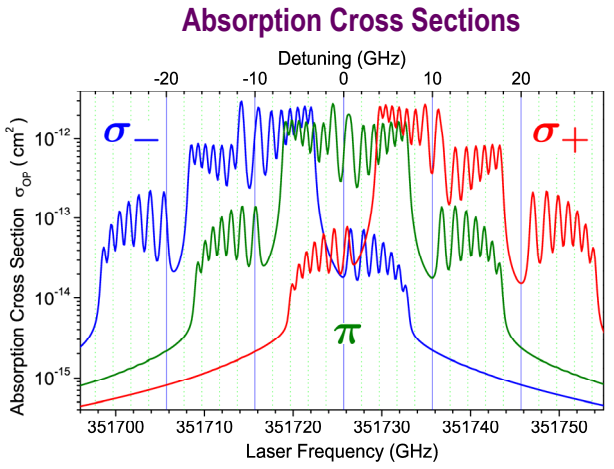
Cs atoms go back and forth between these states because of no quenching in vacuum. During many cycles of optical transition, the nuclear spin attains the angular momentum by $\hbar$ through the mixing of excited state $|J\ 3/2\rangle|Im_I\rangle + \epsilon'|J\ 1/2\rangle|Im_I + 1\rangle$ and the repopulation by spontaneous decay. However, a leak from the cycle is caused by this mixing.

Other overlapping lines work as repumping from $|S{-}1/2\rangle$ to $|S\ 1/2\rangle$. The efficiency of repumping depends on the purity of light polarization. With a little mix of π light, it becomes better to polarize the nuclear spin of atoms in vacuum, then the nuclear spin of salt.

Pressure dependence of spin polarization

Spin Current induced by Optical Pumping − calculation −

Absorption Cross Sections



Numerical simulation at 100 mW/cm², 100℃, 10 Torr N_2 @ 0.56 T