Laser cooling of Cs and quantum sensing towards a search for dark matter

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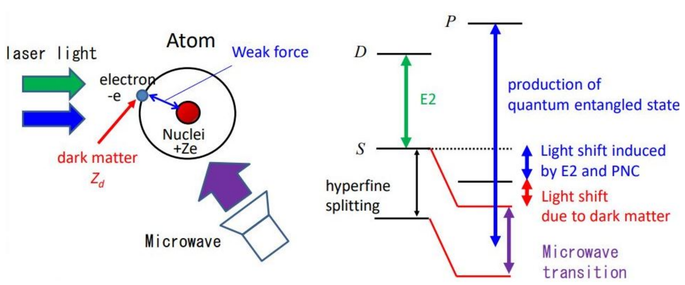
Abstract

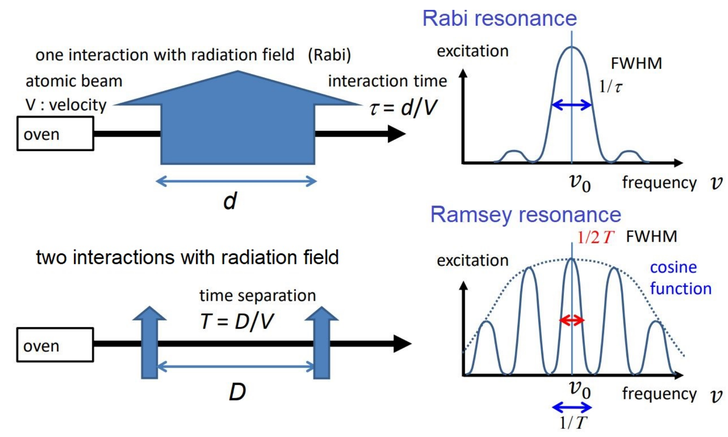
In a search for dark matter, experiments on spectroscopy and laser cooling of Cs are designed to detect this and confirm its existence. In order to enable this, this internship focuses on quantum sensing techniques for accurately observing the Ramsey interferometer for the transition for a microwave transition in the 6s $^2S_{1/2}$ ground state of Cs. We also attempt to observe absorption on the dipole forbidden 6s-5d transition, which is the one that will eventually trigger detectable parity violation and other fundamental effects. We were able to verify and optimize the experimental set-up for observing Ramsey fringes. These observations are promising for the future of the project.

1. Spectroscopy to go beyond the Standard Model



- A method for measuring minutely light shifted atomic levels, in order to obtain experimental data, at odds with current theories, such as parity non-conservation and the existence of dark matter.
- We want to use the knowledge gained from quantum mechanics to measure physical quantities, so-called "quantum sensing", using a magneto-optical trap (MOT).
- The dipole forbidden E2 transition will be used to trigger minute fundamental physics effects

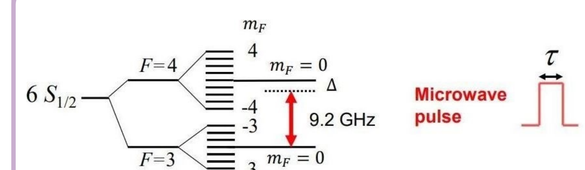
2. Comparaison of Rabi's method with Ramsey's.

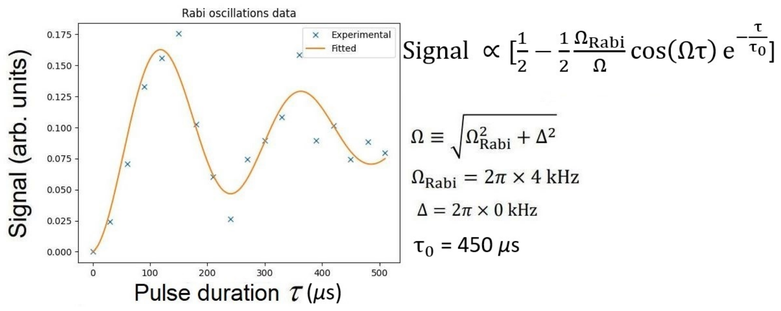


- Using two small separated cavities enables higher resolution spectroscopy than a single long cavity.
- We use the 6s $^2S_{1/2}$, $F = 3$ to 6s $^2S_{1/2}$ $F = 4$ microwave transition (9.2 GHz) to observe Rabi oscillations and Ramsey fringes.

3. Observations that attest to the reliability of our set-up.

3.2 Rabi Oscillations





$$\text{Signal} \propto \left[\frac{1}{2} - \frac{1}{2}\frac{\Omega_{\text{Rabi}}}{\Omega}\cos(\Omega\tau)\, e^{-\frac{\tau}{\tau_0}}\right]$$

$$\Omega \equiv \sqrt{\Omega_{\text{Rabi}}^2 + \Delta^2}$$

$$\Omega_{\text{Rabi}} = 2\pi \times 4 \text{ kHz}$$

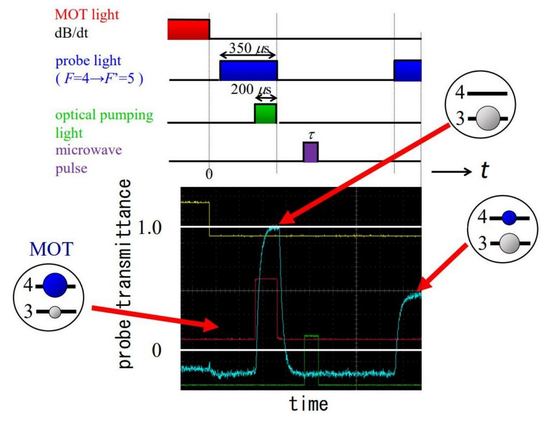
$$\Delta = 2\pi \times 0 \text{ kHz}$$

$$\tau_0 = 450\ \mu s$$

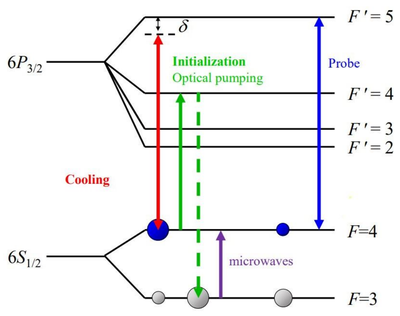
Experimental data and a fit in order to determine Rabi frequency and confirmation of the observation of the Rabi oscillations.

- The vertical axis is proportionnal the number of atoms in the upper state ($F = 4$).
- Measurement for one microwave pulse. The signal received by the detector reflects the probability of finding the atom in the upper state.
- The $e^{-\tau/\tau_O}$ term expresses dephasing.
- The observation of Rabi oscillations confirms that our optical set-up is functional. We can now go a step further and measure the Ramsey interferometer.

3.1 Methodology of our measurements

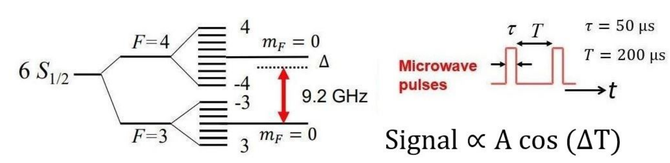


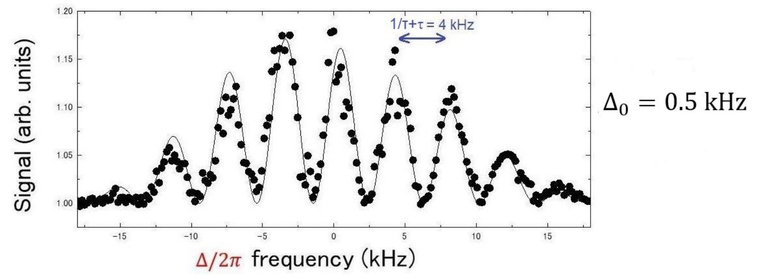
Example of a time sequence and probe transmission presented on the oscilloscope. This example is for just one microwave pulse (Rabi oscillations).



Energy diagram and transitions related to Rabi oscillations and Ramsey spectroscopy. The transitions shown in this diagram are presented in chronological order, from left to right.

3.3 Ramsey Interferometry

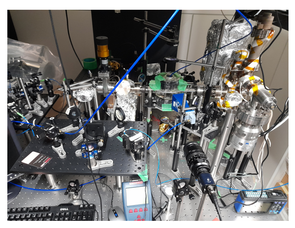




Experimental data with a fit to a theoretical curve. The narrow central fringe is centred on the nominal resonance.

- Measurement using two microwaves pulses. T is the delay between two identical pulses.
- We scan the microwave frequency around the nominal exact resonance ($F = 3$ to $F = 4$) at 9.192631770 GHz.
- Probing the level population after the two pulses, as a function of this detuning Δ, yields narrow Ramsey interference fringes, with the central one being an accurate determination of the exact resonance.
- These measures are promising and take us to the next step $\Rightarrow$ absorption on the 6s–5d line.

4. Perspectives to observe absorption 6s–5d line



- Three pairs of square Helmhotz coils are being installed around the MOT to suppress ambient magnetic fields.
- Spectrally narrow reflectance mirrors will be replaced by gold ones.
- The saturation intensity for the dipole forbidden transition (electric quadrupole) needs to be calculated.

5. Conclusion

This internship has shown that the experimental set-up should enable us to obtain measurements with an accuracy that lives up to expectations. More importantly, the obtained Ramsey interferometry confirms the validity of the method for future measurements of minute shifts of the nominal resonance and confirms the team's ambitions to continue experimenting in line with the proposed model.

[1] Kastberg, A., T. Aoki, B. K. Sahoo, Y. Sakemi, and B. P. Das, 2019, Phys. Rev. A 100, 050101

[2] Aoki, T., R. Sreekantham, B. K. Sahoo, B. Arora, A. Kastberg, T. Sato, H. Ikeda, N. Okamoto, Y. Torii T. Hayamizu, K. Nakamura, S. Nagase, et al., 2021, Quantum Science and Technology 6(4), 044008