Lab Project:
# Hot n' Cold Rubidium
Under Supervision of Dr. Pablo Solano Palma
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Figure 1: sayans!

# Contents

# Summary

The main objective of this project is to study and manipulate the index of refraction of a Rubidium vapour through the interaction with laser light of two different wavelengths. Using a theoretical, numerical and experimental approach, we aim to understand and characterize the Rubidium vapour and the effects of light interacting with this system. The project will be divided into three main stages: theoretical study, numerical simulations, and experimental validation. The theoretical study will focus on the fundamentals of atomic quantum optics, with emphasis on the interaction between light and matter. The numerical simulations will be used to model the interaction between light and Rubidium vapour, and to predict the behaviour of the system under different conditions. Finally, the experimental validation will involve the construction of an experimental setup to measure the index of refraction of the Rubidium vapour and compare the results with the theoretical and numerical predictions. The expected results of this project include a better understanding of the interaction between light and matter, and the development of new techniques for manipulating the index of refraction of Rubidium vapour. This research has the potential to have a significant impact on the field of quantum optics and quantum information processing, and to open up new possibilities for the development of quantum technologies.

As a note, we will reference and quote the work of Arina Tashchilina (found here!) who has provided an amazing source for new students hoping to learn about experimental atomic physics.

# Rubidium

Rubidium is a soft, ductile alkali metal, composed naturally of two stable isotopes, $^{85}$Rb and $^{87}$Rb, in the following ratio; $72.15\%$ corresponds to $^{85}$Rb and $27.85\%$ to $^{87}$Rb The latter is well known in the atomic physics community for being one of the most used elements utilized for laser cooling and realizations of Bose Einstein Condensates (BEC). This is due to the fact that the atomic transitions of rubidium are in wavelengths that are easily accessible by commercial lasers.
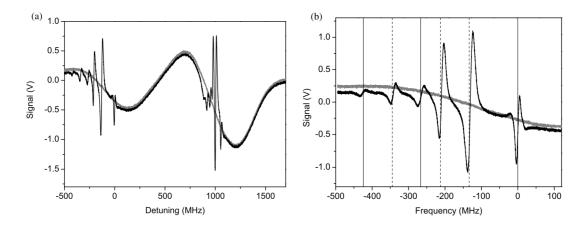


Figure 2: (a) Typical sub-Doppler DAVLL spectra recorded for the F = 2 → F line in 87Rb and F = 3 → F 85Rb (black line). The sub-Doppler features are superimposed on the conventional DAVLL signal (grey line) obtained by blocking the pump beam. (b) A zoomed-in section of (a) showing the sub-Doppler DAVLL signal for the F = 2 → F transitions of 87Rb. Vertical lines indicate the expected line centres of the three transitions (solid lines) and three crossovers (dashed lines). Small discrepancies in the location of spectral features relative to the line centres arise from the slightly nonlinear laser scan. Spectra were taken at a magnetic field of 9.5 G, a pump power of 154 µW and a probe power of 20 µW. doi:10.1088/0953-4075/41/8/085401

## Get those other Lasers paying rent

## How does a Laser Work?

### Laser 1

1. Osciloscope

2. Signal Generator

3. TEC: Temperature Control

4. Control of Control : Lockbox

5. Laser Control : Negative Current Control

6. Current Control

7. Rubidium Heater for Glass Cell



Figure 3: This is what the TEC looks like inside!

### Laser 2

#### Optical Linewidth

Also known as FWHM–HWHM (these concepts are not exactly the same!). This linewidth is where we consider a cavity being resonant. It is usually a Lorentzian distribution. The ideal case of a laser would be a delta distribution in frequency, but even for us physicists, that's too ideal. The linewidth of a light beam is strongly related to the temporal coherence.

### Gaussian Beam

(Check the book of Saleh and Teich, Fundamentals of Photonics for the official reference!)

### Bragg Reflections in Rubidium Vapors

#### How in earth do I find the Rubidium Transition Wavelengths in the experiment?

To start finding the resonances in the DAVLL system (see Fig 2), you first will have to turn on the following (in no particular order, don't worry!):

1. Osciloscope

2. Signal Generator

3. Laser 1 Box

4. Current Control

5. Heaters for the Rb Cell

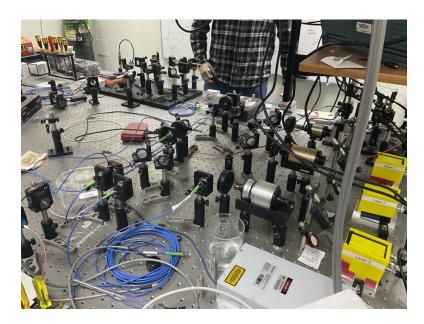6. Photodiodes at the end of the laser path (see Fig 5)

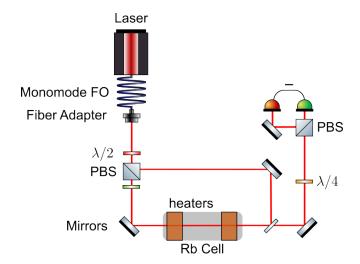Figure 4: Dont be afraid of a "little" mess! Part of the experimental life.



Figure 5: Set up for Laser 1. Dicroich atomic vapor laser lock (DAVLL) system.

## Experimental Set Up

**Rubidium Borosilicate Reference Cell, Ø25.4 mm x 71.8 mm** : Since each fill material is associated with a unique absorption spectrum that serves as its fingerprint, the contents of a reference cell can be determined via a linear absorption measurement (as depicted by the simplified schematic above). By scanning a tunable diode laser over a wavelength range and detecting light absorption (A) with a photodetector, a series of peaks will be recorded, which is characteristic of the vapor inside the cell. All of the cells offered here are baked and evacuated to 10-8 Torr prior to filling in order to remove contaminants. Additionally, each cell is helium leak checked to ensure the longevity of the vapor cell. The vapor pressure of the alkali metal will cause it to migrate throughout the cell and condense at the coolest area. Heating the windows of the cell rather than the cell body will help ensure the windows stay warmer and thus that the alkali will collect elsewhere. If obstruction of the optics becomes an issue, apply cooling to an area on the cell body, such as near the fill stem, and heat the windows in an alternating fashion to drive the metal from the window surfaces and collect it at the cool spot. The metal may eventually move back to the windows depending on how the cell is heated. The rubidium reference cell (GC19075-RB) is sold with the natural isotope ratio of Rb, which is $72.15\%$ $^{85}$Rb and $27.85\%$ $^{87}$Rb

**SM1FCA - FC/APC Fiber Adapter Plate with External SM1 (1.035"-40) Threads, Wide Key (2.2 mm) LA1509-B-ML - Ø1" N-BK7 Plano-Convex Lens, SM1-Threaded Mount, f = 100 mm, ARC: 650-1050 nm**

The Rb vapor cell is a glass cell filled with natural rubidium having two isotopes: 85Rb and 87Rb. The vapor pressure of rubidium inside the cell is determined by the cell temperature and is about $4 \times 10^{-5}$ Pa at room temperature.

## Doppler broadened absorption in a vapor cell

The rubidium atoms in the vapor cell are moving according to the Maxwell-Boltzmann velocity distribution at a temperature of around 400 K. The Doppler broadened lines have line widths of several 100 MHz. This is because even if we detune the probe light by several 100 MHz from the resonance frequency for an atom at rest, there are still atoms within the vapor cell that are moving at the right velocity relative to the wavevector of the light so that they see the light as being exactly on resonance in their center-of-mass frame. Those atoms absorb light from the incident beam, and thereby attenuate the light beam passing through the vapor cell.
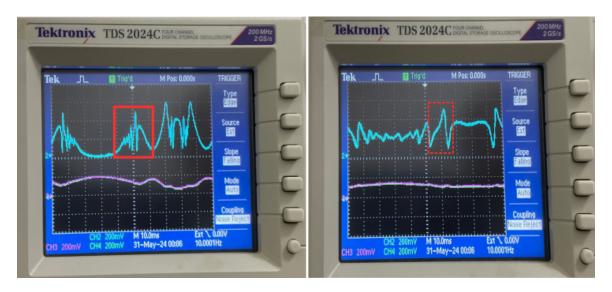
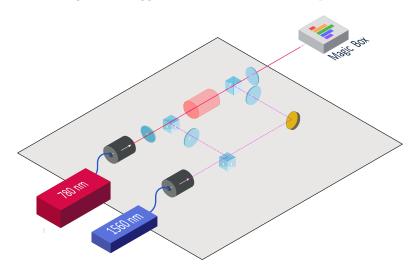Figure 6: Bragg Reflections in Rubidium Vapours.



Figure 7: Set up for the experiment of the bragg Vapours.

## Bragg Reflections in Cold Rubidium

### Experimental Set Up

### MOT - Atom Trapping

Invented at MIT and first demonstrated at Bell Labs [4], it combines the abilities of both cooling and also trapping atoms, limiting both their momenta and their positions, while remaining experimentally simple to implement and to integrate with other experimental needs. Using MOTs and other laser cooling methods, a wide variety of ultracold atomic and molecular gases are produced routinely in labs around the world and applied to a range of scientific pursuits, e.g. matter-wave interferometry with coherent atomic beams, condensed-matter like systems created from quantum-degenerate gases, and novel atomic clocks and other modes of precision measurement.

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https://github.com/aisichenko/MOTorNOT/tree/master/MOTorNOT
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1. Scattering Rate

2. Radiation Pressure

3. Doppler Shift

4. Doppler Cooling

5. Capture Velocity

6. Doppler Temperature Limit and Doppler Molasses

7. Effects of the Zeeman shift on light scattering

8. Sub-Doppler Cooling

9.

## Cooking up (Freezing up?) a MOT

How do we afford to get to these very low pressures ? We have to literally cook the MOT at 100 Celcius for a determined amount of time, this, so we can clear up any impurities that might be present in the chamber. This is a very important step, since the MOT vacuum has to be around $10^{-8}$ Torr.
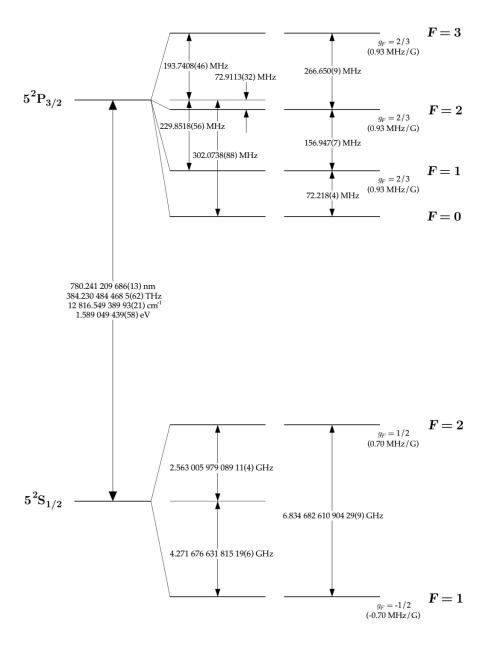
**Atomic Structure**



Figure 8: $^{87}$Rb $D2$ transition hyperfine structure, with frequency splittings between the hyperfine energy levels.The approximate Landé $g_F$-factors for each level are also given, with the corresponding Zeeman splittings between adjacent magnetic sublevels. (Steck, 2001)

# References