I dont know yet

Faustmann Christian

Faculty of Physics
Technical University of Vienna

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Introduction

One of Prof. Rauschenbeutel projects uses a novel type of whispering-gallery-mode (WGM) resonator interfaced via nanowaveguides and coupled to single Rubidium atoms to carry out experiments in the realm of Cavity Quantum Electrodynamics. The WGM resonator is a so-called bottle-microresonator (BMR) manufactured from a standard optical glass fiber in a heat and pull process. The light is radially confined inside the resonator by total internal reflection and propagates along the circumference of the resonator. In such a structure, a signicant fraction of the light field propagates in the evanescent field. By overlapping this field with the evanescent field of an optical nanofiber, light can be coupled into and out of the resonator very efficiently. Due to the extremely low absorption of silica (and low surface roughness) we can produce bottle-resonators with ultra-high optical Q-factor exceeding 10^8. Rubidium atoms are delivered to the resonator using an atomic fountain. For the moment the atoms are only flying by the resonator and when they enter the evanescent field of the BMR, they are coupled to the cavity light field. But only for ~2 μs and moreover the distance between the resonator and the atom is not controlled. This prevents the realization from more complicated experiments. For that reason one needs to trap the atom.

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Chapter 1

Theory of laser trapping of atoms

The strategy pursued to trap is a optical dipole trap. For that the laser light needs to be detuned from a resonance of the atom. Thereafter the atoms are trapped to the maxima of intensity for a red detuned laser. The beam will be reflected from the resonator surface and creates thereby a standing wave. The 1^{st} maxima is at $\lambda_{trap}/4$.

So how to choose λ_{trap}?

Because of the interaction with the BMR evanescent field the atoms need to be trapped really close: $\frac{\lambda}{2\pi} \approx 130\,\text{nm}$
Most common resonance of rubidium is $5S_{1/2} \rightarrow 5P_{3/2}$ @ 780.24 nm. If we use a laser red-detuned from λ = 780.24 nm then our first maxima would be at 195 nm $\Rightarrow$ Not close enough!

But rubidium has another transition from $5S_{1/2} \rightarrow 6P_{3/2}$ @ 420.29 nm, which leads to a distance of 105 nm from the BMR to the 1^{st} maxima. But in the formlula [1] of the trap potenial (U_{dip}) arises the transition strength (Γ) of this specific transition:

$$U_{dip}(\mathbf{r}) = -\frac{\pi c^2}{\hbar \omega_0^3} \left(\frac{\Gamma}{\Delta}\right) I(\mathbf{r}) \tag{1.1}$$

We have to compare this potential to the kinetic energy of our rubidium atoms. The atoms fall approximately 60 ms and the corresponding kinetic engergy would be $E_{kin} = \frac{1}{2} m_{Rb} v^2$. In terms of temperature we would get: $\frac{E_{kin}}{k_B} = 1.77\,\text{mK}$. This is quite huge for a dipole trap. For that reason one needs to know $\Gamma_{420nm-Line}$ and one also needs to have a trap with a small detuning. This requires to see the transitions to have a reference to lock the laser afterwards. To determine $\Gamma_{420nm-Line}$ we can use the relation with the intensity saturation:

$$I_{sat,420} = \frac{\Gamma_{tot,420} \times \omega_{420}^3 \times I_{sat,780}}{\Gamma_{420} \times \Gamma_{780} \times \omega_{780}^3} \tag{1.2}$$

$$\text{with} \quad \Gamma_{tot,420} = \frac{1}{total\ lifetime\ of\ 6P_{3/2}\ state}$$

$\Rightarrow$ We want to measure I_{sat} for the blue 420.29 nm-line.

Chapter 2

Absorbtion of photon by an atom

The purpose of this section is to outline the basic features observed in saturated absorption spectroscopy and relate them to simple atomic and laser physics principles. For this we will follow the guidance of [2].

2.1 Laser interactions - Two-level atom

In the upcomming sections we will derive an expression for the absorption or to be precise the intensity of the laser beam, but first we need a model on which basis we will do this.

The simplest model is the two-level atom with a groundstate $|g\rangle$ and one excited state $|e\rangle$. There are three possible transitions:

(1) stimulated absorption

(2) stimulated emission

(3) spontaneous emission

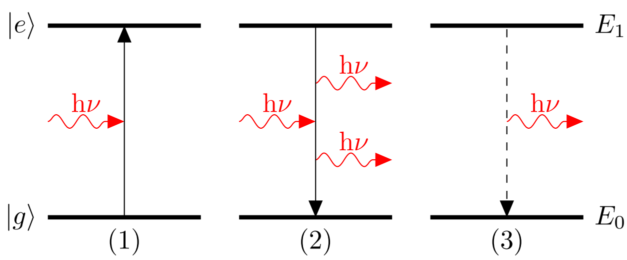

Fig. 2.1 Two-level atom model

In our case we will only consider the photon absorption, because emission is isotropic. If we only consider absorption than the following expression describes the decrease of the intensity in the rubidium cell:

$$I(x+\mathrm{d}x) - I(x) = -I(x)h\nu\alpha n(P_0 - P_1)\mathrm{d}x \tag{2.1}$$

where:

$\alpha I(x)$ ... stimulated transition rate

n ... atom density

P_0 ... proportion of atoms in $|g\rangle$

P_1 ... proportion of atoms in $|e\rangle$

2.2 Absorption coefficient

Out of equation (2.1) we define the absorption coefficient κ:

$$\kappa = h\nu\alpha n(P_0 - P_1) \tag{2.2}$$

With the next steps we wanna decribe the different parameters and derive κ with all its dependencies. For this we will follow the guidance of [2].

$h\nu$ is the excitation energy for the atom to change from ground $|g\rangle$ to excited state $|e\rangle$.
From the stimulated transition rate α denotes:

$$\alpha = \alpha_0 \mathcal{L}(\nu, \nu_0) \tag{2.3}$$

where

$$\alpha_0 = \frac{2\pi\Gamma}{I_{sat}} \tag{2.4}$$

$$\mathcal{L}(\nu, \nu_0) = \frac{1}{1 + \frac{4(\nu-\nu_0)^2}{\Gamma^2}} \tag{2.5}$$

2.3 Doppler shifts

2.4 Behavior of absorption coefficient

2.5 Non-linear differential equation

2.6 Relevant data

	Rubidium	
Isotope	85	87
Atomic mass	84.911794	86.909187
in 10^{-25}kg	1.40999	1.44316
Abundance	72.17%	27.83%
Spin I	$5/2$	$3/2$
lifetime $6^2P_{3/2}$	112 ns	
Natural linewidth	$2\pi \times 1.421$ MHz	

Table 2.1 Properties of rubidium isotopes

2.7 D2 line

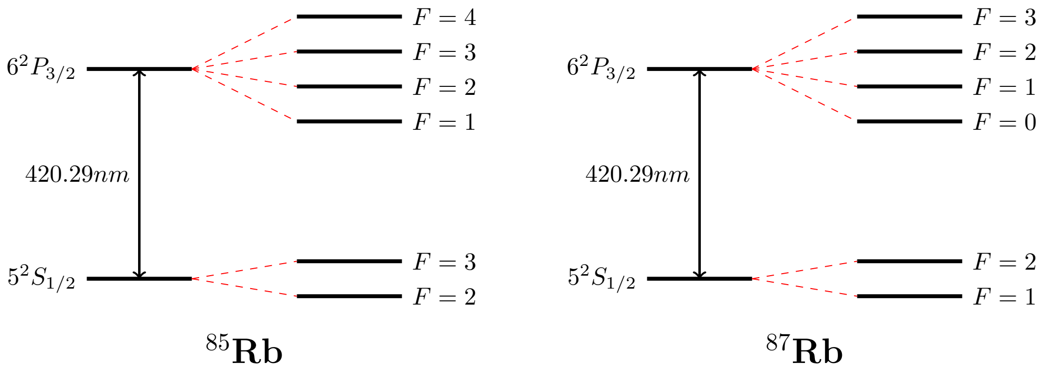

Fig. 2.2 $5^2S_{1/2} \rightarrow 6^2P_{3/2}$ transition of ^{85}Rb and ^{87}Rb with corresponding hyperfine structure

The transition of interest is, as we have discussed before, the $5^2S_{1/2} \rightarrow 6^2P_{3/2}$ of rubidium. As known rubidium occurs in two isotopes, ^{85}Rb and ^{87}Rb. As we can see both isotopes have the same transition energy, but due to the different spin I (see table: 2.1) we get different energy levels for the groundstate [3]. This is the reason why we wittness four doppler peaks in our spectrum.

Caution: Both figures below show the correct correlation between energy and isotopes. The reason for this is that the spectrum shows transition energy and the other one the specific energy levels.

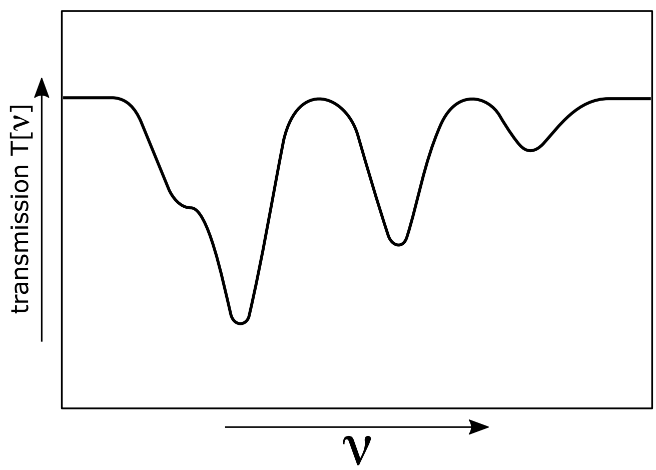

Fig. 2.3 Doppler spectrum of D2 line

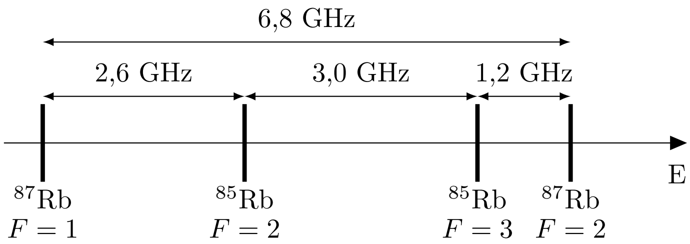

Fig. 2.4 Relative energy gaps of the groundstates between both isotopes

Chapter 3

Experiment

3.1 Setup & Tools

3.2 Laser diameter measurement

3.3 Power / intensity measurement

3.4 Doppler-free measurement

Chapter 4

Evaluation

References

[1] R. Grimm, M. Weidemüller, and Y. B. Ovchinnikov. Optical Dipole Traps for Neutral Atoms. *Advances in Atomic Molecular and Optical Physics*, 42:95–170, 2000.

[2] Department of Physics. Saturated absorption spectroscopy. *University of Florida*, 2001.

[3] J. Reader A. Kramida, Yu. Ralchenko and NIST ASD Team (2015). NIST atomic spectra database (ver. 5.3). *National Institute of Standards and Technology*, 2015.

Appendix A

Theory

Appendix B

Experiment

Appendix C

Evaluation