Determination of Isotopic Ratio of a sample of Natural Rubudium using Laser Absorption Spectroscopy

Challenger Mishra- (challenger@iiserk.net)
Sambit Bikas Pal- (sambit@iiserk.net)

Indian Institute of Science Education and Research, Kolkata

December 23, 2007

MOTIVATION

- In open path spectroscopy, tunable diode lasers (TDLs) are designed to focus on single absorption wavelengths specific to a compound of concern in the gaseous form.
- They are capable of achieving low detection. Open path TDLs are used in atmospheric pollutant studies, process line/tank leak detection, industrial gas-purity applications, and detection of poisonous gases even in low quantities in hazardous environments like mines.
- To get some hands on experience in the field of LASER absorption spectroscopy using TDL, we tried estimating the isotopic ratio of ^{85}Rb and ^{87}Rb in a given sample containing natural Rubidium.

INTRODUCTION

- The $5^2P_{\frac{3}{2}}$ excited state in Rubidium lies an energy equivalent of 780 nm above the $5^2S_{\frac{1}{2}}$ ground state.
- The absorption spectrum is due to $5^2P_{\frac{3}{2}}$ - $5^2S_{\frac{1}{2}}$ transition in rubidium (Rb).
- Doppler broadened absorption spectrum is used to determine the ratio of the two stable isotopes of Rubidium.
- The variation of Doppler width with temperature is investigated.

BROADENING OF ATOMIC SPECTRUM

- **Lifetime Broadening**- An excited atom can emit a photon via stimulated or spontaneous emission. The photon energy will be equal to the energy difference between the final and the initial state.However, the following prevents us from knowing this energy difference precisely.
  $\Delta E * \Delta t \;\geq\; \frac{h}{4\pi}$
  Emission lines therefore have finite widths. Excited atomic states have a typical lifetime of 10^{-8} s. This corresponds to a natural line width for emission lines of the order of $6 * 10^{-8}$eV or 15 MHz. Absorption lines also exhibit this broadening.
- **Doppler broadening**- If an atom is moving toward or away from a laser light source, then it "sees" radiation that is blue or red shifted, respectively. $\nu = \nu_0(1 \pm \frac{v}{c})$ is well known.
- At high pressures, perturbations of the energy levels by collisions, **pressure broadening**, can become the limiting factor for the resolution. **Power broadening** occurs because of the shortening of the lifetime of the excited states due to stimulated emission.

BROADENING OF ATOMIC SPECTRUM

The half width of the Doppler broadened line, is given by
$\Delta\nu_{\frac{1}{2}} = 2.92 * 10^{-20}\nu_0(\frac{T}{M})^{\frac{1}{2}}$
where M is the mass of the absorbing atom in kilograms and T is the absolute temperature in Kelvin. So the FWHM of a Doppler broadened line is a function of ν_0, M, and T

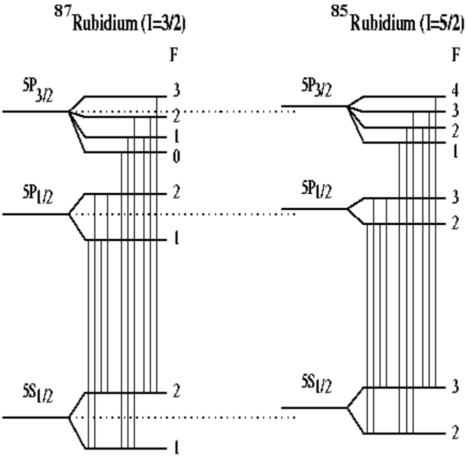
HYPERFINE STRUCTURE OF RUBIDIUM

- The ground state electron configuration of rubidium (Rb) is: $1s^2; 2s^2, 2p^6; 3s^2, 3p^6, 3d^{10}; 4s^2, 4p^6; 5s^1$.
- The first excited state is produced when the single 5s electron becomes a 5p electron, and no core electrons are excited.
- Natural rubidium has two isotopes with different nuclear spin quantum numbers I viz $^{87}Rb, I = 3/2$ and $^{85}Rb, I = 5/2$.
- A transition between some hyperfine sublevel in the $5^2S_{\frac{1}{2}}$ state and a hyperfine sublevel in the $5^2P_{\frac{3}{2}}$ must satisfy the selection rules

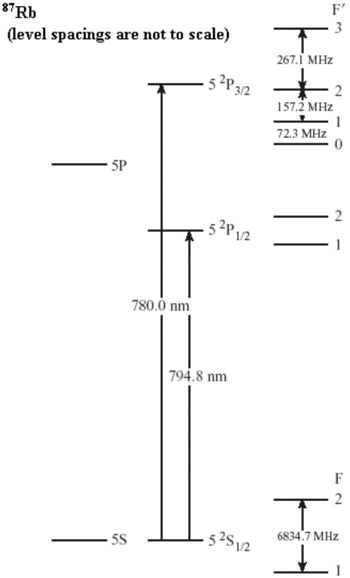
$$\Delta f = 0, 1, \Delta j = 0, 1, \Delta l = 1, \Delta m_f = 0, 1 \tag{1}$$

- Here we are concerned with only the fine structure of Rubidium and look at the transition from $5S_{\frac{1}{2}}$ state to $5P_{\frac{3}{2}}$ state.

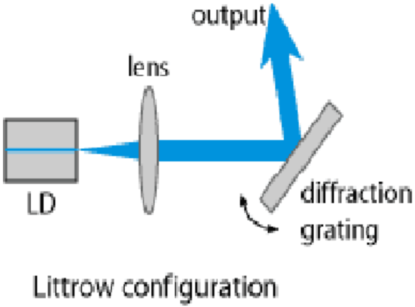
HYPERFINE STRUCTURE OF RUBIDIUM



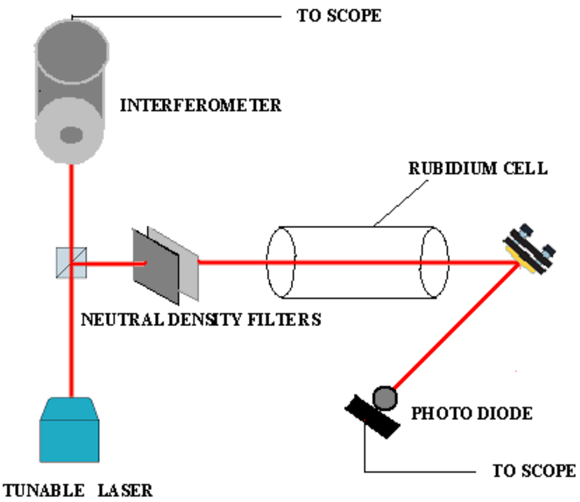
HYPERFINE STRUCTURE OF RUBIDIUM



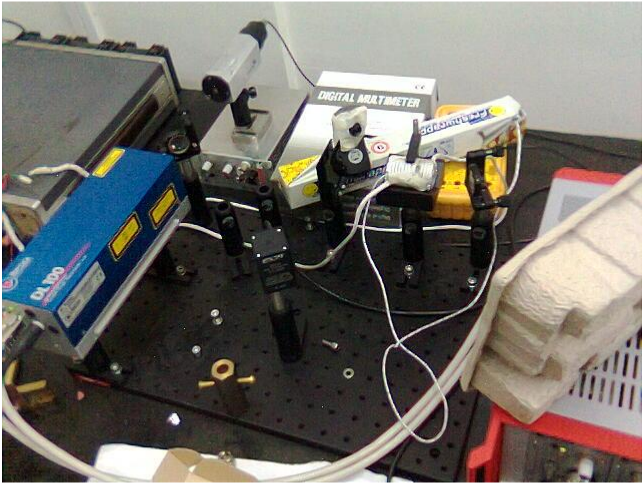
TUNABLE DIODE LASER



EXPERIMENTAL SETUP



EXPERIMENTAL SETUP



RESULTS

- The absorption spectrum of each isotope follows the Gaussian distribution given in terms of the line width parameter (delta)

$$P(\nu)d\nu_L = \frac{2}{\delta\pi^{1/2}} exp[\frac{-4(\nu_L - \nu_0)^2}{\delta^2}]d\nu_L$$

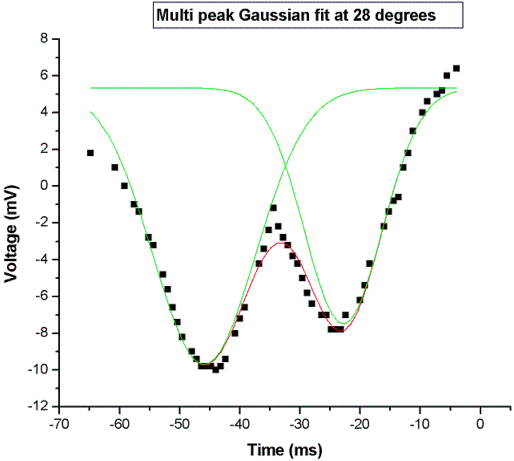
where

$$\delta = 2\frac{\nu_0}{c}(\frac{2kT}{M})^{\frac{1}{2}}$$

- The following was used to fit the oscilloscope data

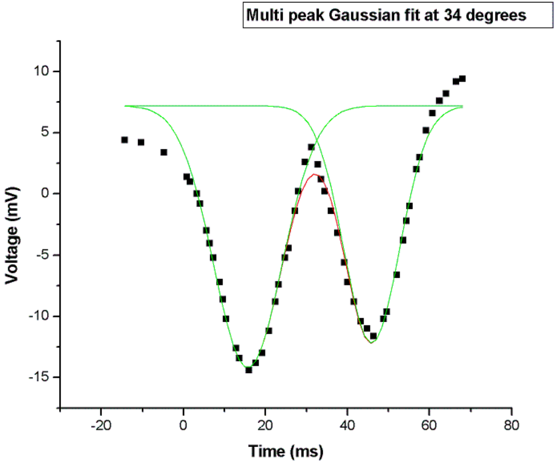
$$y = y_0 + \frac{A}{w\sqrt{\frac{\pi}{2}}} e^{-2\frac{(x-x_c)^2}{w^2}}$$

RESULTS

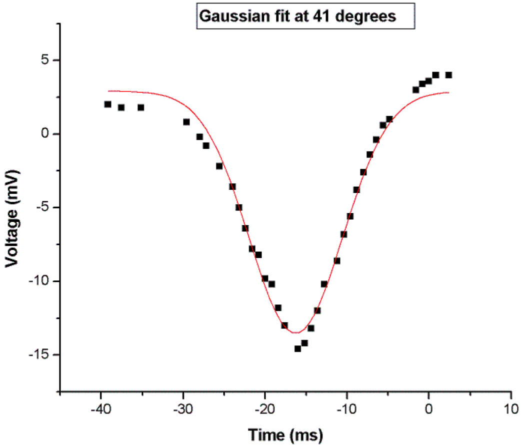


Multi peak Gaussian fit at 28 degrees
8
6
4
2
0
-2
-4
-6
-8
-10
-12
Voltage (mV)
-70
-60
-50
-40
-30
-20
-10
0
Time (ms)

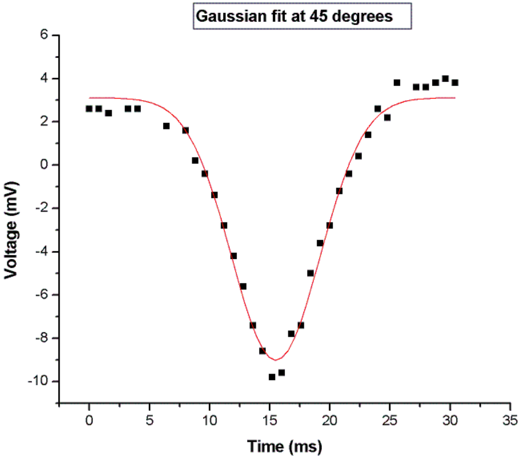
RESULTS


Multi peak Gaussian fit at 34 degrees
Voltage (mV)
10
5
0
-5
-10
-15
-20
0
20
40
60
80
Time (ms)

RESULTS


Gaussian fit at 41 degrees
Voltage (mV)
5
0
-5
-10
-15
-40
-30
-20
-10
0
10
Time (ms)

RESULTS



Gaussian fit at 45 degrees
Voltage (mV)
6
4
2
0
-2
-4
-6
-8
-10
0
5
10
15
20
25
30
35
Time (ms)

RESULTS

Table 1. Doppler width and isotopic ratio at various temperatures.

Srl. No.	LASER current (mA)	Temperature (Kelvin)	Doppler Width of ^{85}Rb (GHz)	Doppler Width of ^{87}Rb (GHz)	Isotopic Ratio (^{85}Rb: ^{87}Rb)
1	98	301	0.258+/-0.0089	0.196+/-0.0082	1.54+/-0.16
2	98	307	0.259+/-0.0086	0.211+/-0.0083	1.36+/-0.13
3	98	314	The absorption dips merged	0.176+/-0.0018	Cannot be inferred from data
4	99	318	The absorption dips merged	0.236+/-0.0070	Cannot be inferred from data

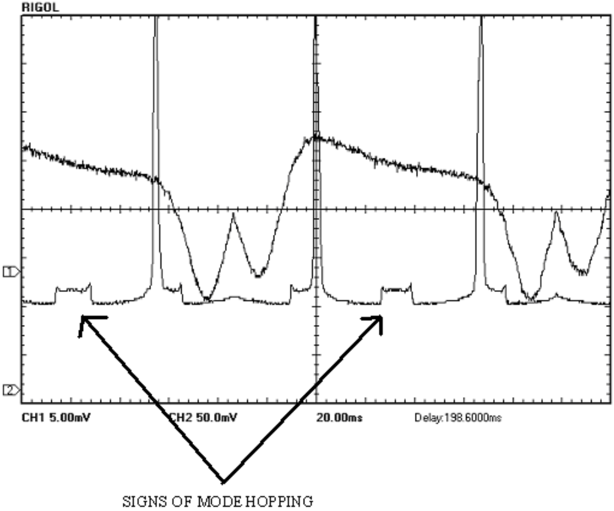
ANALYZING THE RESULTS

- The isotopic ratio $^{85}Rb :^{87} Rb$ was found to be 1.54 ± 0.16 at 301 K and 1.36 ± 0.13 for 307 K.
- The expected ratio is 2.57
- The Doppler width for each of the isotopes is seen to increase with temperature from the 1st two readings.
- As the temperature increased, the Doppler width of both the isotopes increased enough to merge into each other to give a single broadened absorption dip.
- This width also increased as the temperature increased. $\Delta\nu_{\frac{1}{2}} = 2.92 * 10^{-20}\nu_0(\frac{T}{M})^{\frac{1}{2}}$

ANALYZING THE RESULTS

- Diode lasers under certain conditions discontinuously switch wavelengths. This is known as mode hopping.
- When mode hopping occurs, many wavelengths are emitted simultaneously, making it impossible to tune the laser at this point.
- Mode hopping can occur even when the lasers case temperature and current are tightly controlled.

MODE HOPPING

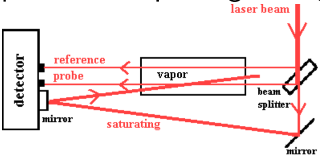


THE BIG FLAW !!

- The scanning amplitude of the Laser was kept too low to include the absorption dip of both the isotopes
- The mirror images of one of the absorption dip was mistaken to be the absorption of the other

FUTURE WORK

- The isotopic ratio of the Rubidium could not be truly obtained.
- It still remains to be verified that the Doppler width is proportional to the square root of the Temperature.
- The hyperfine structure of each isotope can be determined using Doppler free spectroscopy with a similar experimental set up using a pump beam and a probe beam passing through



the cell from opposite directions.

ACKNOWLEDGEMENT

- Dr. Satyajit Saha, SINP
- Dr. Debades Bandopadhyay, SINP
- All other members of CARE

REEERENCES

- 'Mode Hopping in Semiconductor Lasers'.T.A. Heumier and J.L. Carlsten, Department of Physics, Montana State University.
- http://electron9.phys.utk.edu/optics507/modules/m10/saturation.htm
- User manual TOPTICA DL 100
- The Doppler Effect University Physics 11th Edition, Sears and Zemansky.
- http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html
- Doppler-free Spectroscopy, Lab Manual, MIT Department of Physics.

THANK YOU !!