Saturation spectroscopy of Rb using a tunable diode laser

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This paper includes information on absorption spectroscopy of Rb atoms for use in an atom trapping experiment. It includes detailed instructions on the setup and procedure for observing Doppler broadened and Doppler free spectrum using a tunable diode laser.

I. Introduction

Using a tunable diode laser is an easy method for doing atomic spectroscopy[1]. In this experiment we are interested in the spectrum of Rb atoms.

Rb was chosen because it is the gas that will be used in the follow up atom trapping experiment. There are various absorption lines in the Rb gas and these correspond to particular atomic transitions. These transitions play an important role in the trapping of atoms[3].

This experiment starts by observing the Doppler broadened absorption lines followed by a saturated absorption for Doppler free lines.

The saturated absorption experiment is a good way to examine the stability of your tunable diode laser. Good stability will be required in the atom trapping experiment.

The long-term goal is to not only observe the atomic transitions but to lock onto one. This can be accomplished by having external feedback control of the diode laser.

II. Components

Rubidium vapor cells are commercially obtainable but can be expensive. If you do now wish this expense and have the facilities needed to make your own cells then refer to reference 1 for detailed instructions on making your own vapor cells.

A tunable laser is required for this experiment. The laser frequency needs to be easily adjustable to scan over absorption lines in Rb. Reference 2 contains instructions on the design of a tunable diode laser using optical feedback. This is an inexpensive and easily constructed laser, which can be tuned to specific wavelengths very easily.

The optical components required are at least two mirrors, a beam splitter, mirror mounts, and a stand to hold the Rb cell. The mirrors should be gold plated so they are more reflective in the infrared. No mirrors are required for the Doppler broadened spectrum. For the saturated absorption setup you will need at least two mirrors depending on your arrangement. These two setups are discussed in more detail later in this paper and are show in figures 3 and 4.

The final components of this experiment are for data acquisition. Data is taken as the laser is scanning through different frequencies. We used a tunable diode laser, discussed earlier so a triangle wave generator was required to control the piezo disc. Two photo diodes will be used, one if you are only doing the Doppler broadened line. We used a high-speed silicon detector, DET110. An oscilloscope or some similar device is needed to observe and record the detector output.

III. Frequency Scale of Light

In this paper we will be using the Hz scale for EM waves instead of frequency. So I will give a summary on how to understand and convert between the two.

In these experiments the scales used are in the MHz and GHz range. A change of frequency of 100 MHz corresponds to a wavelength shift of about $2.028e^{-4}$ nm and a change of 10 GHz corresponds to roughly $2.028e^{-2}$ nm. Theses can be figured using the following equation in figure 1.

$$c = \lambda f$$

This is the standard relation between wavelength and frequency.

Figure 1

Using this you can calculate wavelengths for specific frequencies and determine the change in wavelength for a given change in frequency.

IV. Rb Cell and absorption lines

The Rb cell contains two Rb isotopes: Rb^{85} and Rb^{87} and Cs. Absorption

$$\frac{1}{2}kT = \frac{1}{2}mv_{rms}^{2}$$

Energy in one direction for a gas at temperature T.

$$\frac{\Delta f_{FWHM}}{f_0} = 2.3\frac{v_{rms}}{c}$$

This is the equation for the broadening of the frequency due to the Doppler shift.

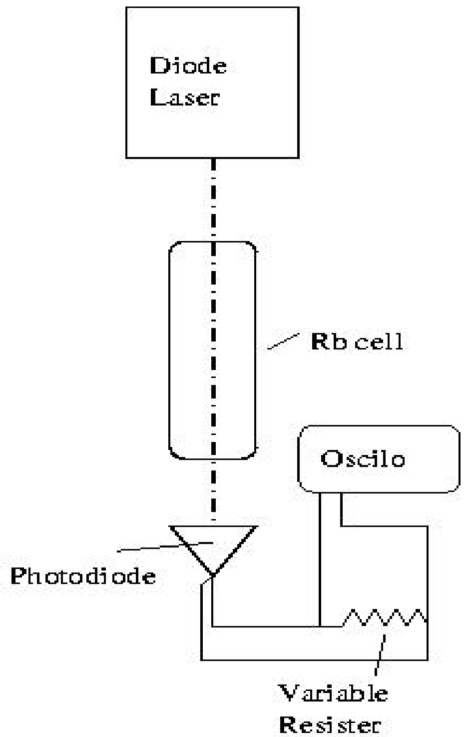
Figure 2

occurs in Rb at 780 nm and in Cs at 852 nm.

There are 4 Rb absorption lines, two for each isotope. These four lines are separated by roughly 8 GHz and each line is Doppler broadened. This broadening can be calculated with the following equations in figure 2[4].

Using these equations the broadening of the absorption lines at room temperature was calculated to be 500 MHz[4]. The saturated absorption setup eliminates this broadening allowing the selection of a particular absorption line.

Finding these transitions allows you to find particular atomic transitions in the Rb. There are two transitions of particular interest for an atom trapping experiment[3].



The layout for spectroscopy of the Doppler broadened absorption lines.

Figure 3

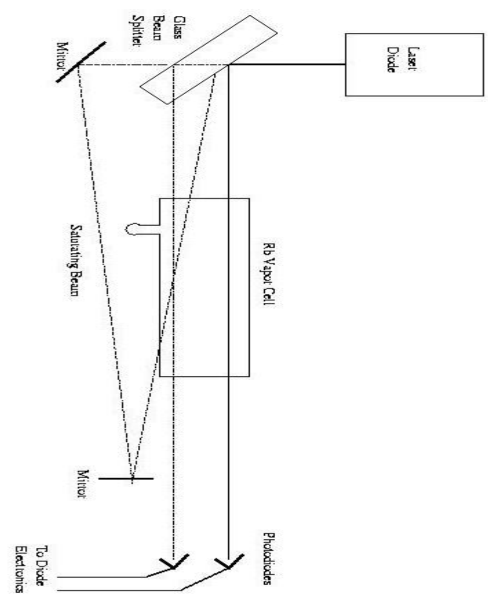
To trap Rb^{87} you tune to a frequency on the low side of the $5S_{1/2}F=2 \rightarrow 5P_{3/2}F'=3$ transition. The problem occurs when approximately one out of 1000 atoms decay to the F=1 state instead of the F=2 state. This takes the atom out of resonance with the laser. This will continually remove atoms from the trap. To solve this problem a second pumping laser is set to excite the transition from 5SF=1 to 5PF'=1 or 2 state. This state will decay back into the 5S F = 2 state putting the atom back in resonance with the trapping laser[3].

V. Absorption Set up

The first absorption setup is the Doppler broadened profile. This is just passing the laser beam straight through the Rb cell onto a photodiode. The photodiode current is converted into a voltage and viewed on an oscilloscope. This setup is show in figure 3. It is a good starting point because the setup is not complicated and the resolution does not need to be as high as in the saturated absorption.

The second setup will involve two beams. The first beam is a reference beam like in the previous setup. It will be the Doppler broadened beam. The second beam is the saturated beam. The setup is shown in figure 4. The saturated beam will contain more fine structure of the absorption spectrum then the Doppler broadened one. These two beams are then monitored by the photodiodes.

The final procedure is to monitor the voltage from both the non-saturated and



The layout of the saturated absorption setup for the Doppler free spectroscopy of Rb

Figure 4.

saturated beams simultaneously. The outputs of the photodiodes when subtracted will produce the Doppler free spectrum of the Rb.

VI. Piezo Scanning

The tunable diode laser should be set to a wavelength near 780 nm. This is done by controlling the temperature along with the course adjustment made by rotating mirror mount to change the cavity length. This will get you close to an absorption line but it is hard to sit on a particular line or sweep through the line in a controlled manor. The piezo electric disc is used for the fine control of the wavelength.

First we set the DC offset control to adjust the wavelength until we were sitting on or near an absorption line.

Next using the triangle wave generator we scanned for absorption lines. The triangle wave was set to between 15 and 30 Hz with peak-to-peak amplitude of 30 V as explained in reference 1. We tried various frequencies between 15 and 30 Hz. Controlling the amplitude of the wave should allow for selection of a particular absorption line. The spacing between absorption lines is around 8 GHz. With the piezo at 30 V peak-to-peak amplitude it will be sweeping through multiple lines[2].

VII. Results

The oscilloscope imaging from the Doppler broadened absorption setup was unclear. There were definite areas of absorption seen. We were not able to get clear enough images to really understand what was being seen.

One problem was the amplitude of the triangle wave generator. The peak-to-peak voltage was too large to zoom in on one absorption line. The attenuator on the wave generator also attenuated the DC offset making it impossible to have a small enough peak-to-peak amplitude and still offset the piezo to be on the center of a line. Without the attenuation the amplitude was large enough that it would scan through more then one absorption line at a time.

[1]C. Wieman and L. Hollberg, “Using diode lasers for atomic physics,” Rev. Sci. Inst. **62**, 1-20 (1991)

[2]J. Millspaw, “A narrow-band tunable diode laser with optical feedback control,” Phys. 670F, Purdue University, Physics Department, West Lafayette, IN, 47906

[3]C. Weiman and Gwenn Flowers, “Inexpensive laser cooling and trapping experiement for undergraduate laboratories,” Am. J. Phys. **63**(4), April 1995

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