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An Investigation into Observing Absorption and Doppler-free Saturated Absorption Spectra of Rb

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Abstract

The thrust of this project was to create a detailed set of instructions for setup and procedure for observing the Doppler broadened and saturated absorption of rubidium using a tunable laser diode. These experiments can be used to determine the short and long term frequency stability and tuning behavior of the laser frequency. [1]

The purpose of this project was to develop a simple and inexpensive way to use a commercial infrared laser diode to observe Doppler broadened absorption lines and Doppler-free saturated absorption lines for rubidium. This set-up was designed with the future project of atom trapping in mind (see reference 4). Atom trapping requires a stable and tunable laser diode over narrow-band width. This project provides an easy and sufficient basis for testing the stability and control of a laser diode system. Many of the ideas included here came directly from K.B. MacAdam and Carl E. Wieman as referenced.

Rubidium contains four atomic resonance lines corresponding to energy differences in electron energy levels. In order to excite these particular absorption lines you need photons of a specific wavelength. If you can tune a laser diode to these particular wavelengths (around 780 nm for Rb) you can pass the emitted light through a rubidium vapor cell causing the Rb atoms to absorb the photons rather than letting them pass through. This is referred to as Doppler broadened absorption. During Doppler broadened absorption you can observe, with a CCD camera or IR viewer, fluorescence in the cell as the electrons return to their original levels.

During the saturated absorption experiment you should overlap two beams in the rubidium cell, which will cause small saturated absorption dips to become evident near the center of the absorption line. Then by subtracting off the Doppler broadened profile (seen simultaneously with a third beam) the saturated absorption features will appear on a nearly flat background. [1]

Our particular results were sketchy; therefore I have included examples of data, obtained from MacAdam, to help with the explanations.

List of our components:
laser diode system as described in reference 3
rubidium cell
CCD camera and television for viewing fluorescence
at least two gold plated mirrors
mirror mounts
3/8-inch thick transparent plastic or glass and mount
triangle wave generator (we used ………)
2 photodiodes (we used High-Speed Silicon Detectors from Thorlabs (model: DET110))
1 variable resistor
Some way of reducing vibrations (we used rubber o-rings and steel plate layers).
An oscilloscope or similar device capable of XY-mode for observing and recording voltages from the PZT disk on X and voltages from photo diodes on Y.

Absorption lines of Rb:

The rubidium cell contains Rb^{85} and Rb^{87}. There are two absorption lines for each isotope. Each of these lines can be Doppler broadened to approximately 700Mhz at full-width half-max (calculated using equation 1 and 2). The saturated absorption experiment with the Doppler broadening subtracted out will cover approximately 500 MHz. [1]

Equation 1:

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

Equation 2:

$$3/2 \;\; kT = 1/2 \; mv^2$$

Doppler Broadened Setup:

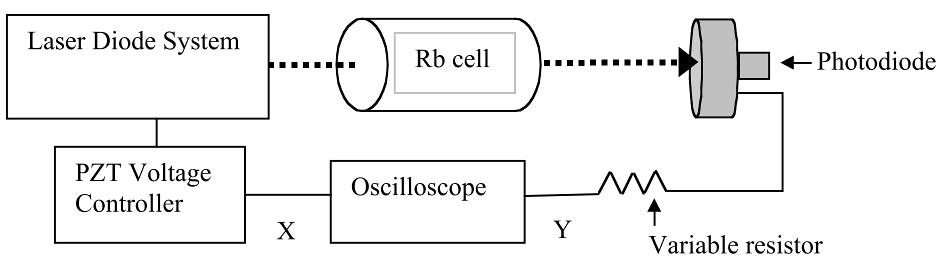
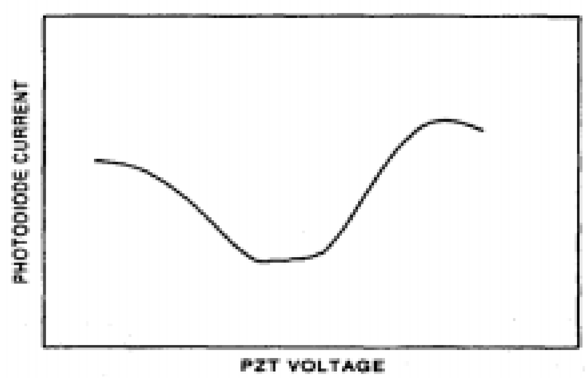


Figure 1

The setup for the Doppler broadened profile of an absorption line is fairly straightforward. We used the laser diode system described in reference 3. Set the rubidium cell in the direct path of the beam and placed one photodiode also in the beam path on the other side of the vapor cell (see figure 1). We advise you start with this setup as it is easy to align and provides a preliminary assessment of your mechanical, electrical, and thermal stability. [1] It also allows you to get a feel for how to narrow in on one fluorescence line. The beam should be attenuated so the intensity is less than 3 mW/cm^2.

The piezoelectric disk should be driven by a triangle wave generator at 15 to 30 Hz, with a peak-to-peak amplitude up to 30V. [1] If you are not on or near an absorption line you should first adjust the DC offset until you can see fluorescence flickering in and out. It is helpful to watch the oscilloscope in XY-mode as you adjust the PZT amplitude, offset voltage, and frequency. [1] Scanning between 15 and 30 Hz you should be able find a strong area of fluorescence stable enough to zoom in on. You will notice that there may be several features similar to Doppler broadening visible on the oscilloscope, these correspond to two or more of the four atomic transition lines. To zoom in on one Doppler broadened line (see example 1) lower the amplitude of your triangle wave generator. This will zoom in on the line in the center of your oscilloscope, however you can shift the lines right or left by shifting your DC offset up or down. You may also find it helpful to change the variable resistor value to achieve the most desirable graph.



Example 1: Modified figure 12 from MacAdam

Saturated Absorption Setup:

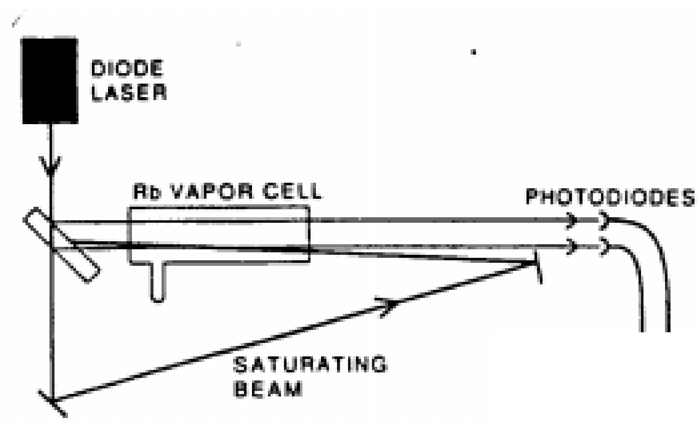
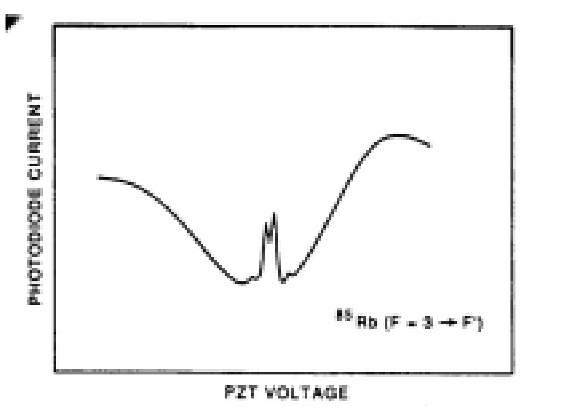


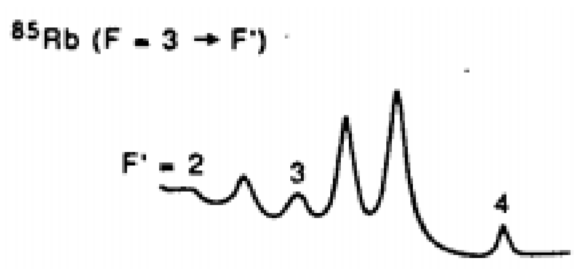
Figure 2: Taken from MacAdam (Fig. 10)

The setup for the Doppler-free saturated absorption is more complicated and requires greater stability. Figure 2 details the setup described herein. This setup requires three beams, two probe beams of about 2% intensity each and one saturating beam of about 96% intensity. You can easily obtain the three beams by passing the laser through a 3/8-inch piece of transparent glass or plastic and utilizing the reflections off both front and rear surfaces. [1] The first probe beam (reflection off front surface) will pass through the rubidium cell and into a photodiode. This provides a Doppler broadening reference that we will subtract off later. The second probe beam will also pass through the rubidium cell and into a second photodiode, but it will be crossing the saturating beam in the center of the cell at a 1° angle. You must use at least two mirrors to get the saturated beam back into the cell. The mirrors should be gold plated because gold reflects IR better than the standard mirror. We found it easier to setup and align our optics using a visible laser. To use this approach you should define you beam path with two slits so when you replace your visible laser with the IR laser it will be aligned when it passes through the two slits. If a visible laser cannot be obtained, we suggest using a CCD camera and IR card for optics alignment.

When adequate saturated and probe beam overlap has been obtained, small saturated absorption dips will become evident near the center of the Doppler broadened line [1] (see example 2). To get the Doppler free spectrum of rubidium you will need to subtract the Doppler broadened profile of the reference beam from the saturated absorption. This will allow the saturated absorption features to appear on a nearly flat background (see example 3).



Example 2: Taken from MacAdam (Fig. 12)



Example 3: Modified Figure 13-a from MacAdam

Results:

Our oscilloscope imaging of the Doppler broadened absorption setup was unstable. We could see the Doppler broadened absorption (see example 1), but it would slide on and off the oscilloscope from right to left making it impossible to save the image. Upon further examination into this problem we discovered that the attenuator on our triangle wave generator also attenuated the DC offset. This made it difficult to have a small enough peak-to-peak amplitude and still be able to use the offset to center on one absorption line. There may be more to this problem, therefore I suggest a more through investigation into this experiment and its stability difficulty.

References:

[1] MacAdam, K.B., Steinbach, A., and Wieman, C., "A narrow-band tunable diode laser system with grating feedback, and a saturated absorption spectrometer for Cs and Rb," American Journal of Physics, vol.60, no.12, December 1992, pp. 1098-1111.

[2] Wieman, Carl E., "Using diode lasers for atomic physics," Rev. Sci. Instrum, vol.62, no.1, January 1991, pp. 1-20.

[3] K.L. Adams, "Controlling the Wavelength of a laser Diode," PHYS 670F, Spring Semester 2000, S.M. Durbin, Physics Department, Purdue University

[4] Wieman, Carl E., "Inexpensive laser cooling and trapping experiment for undergraduate laboratories," American Journal of Physics, vol.63, no.4, April 1995, pp.317-30.