

DOPPLER FREE SATURATED ABSORPTION SPECTROSCOPY

Background Reading: Demtröder, Wolfgang. *Laser Spectroscopy*. Springer-Verlag, 1981. Sect. 3.2 and 10.2, pp.84-89 and 484-494.

I. PURPOSE

This experiment is designed to acquaint students with modern optical techniques and procedures. You will first study the normal Doppler broadened absorption of Rubidium using a tunable diode laser. To go beyond the Doppler resolution limits of traditional spectroscopy, you will employ the saturated absorption technique.

II. INTRODUCTION

Absorption spectroscopy has its roots in the very beginning of modern physics. It is based on the principle that electrons lie in quantized energy states in all atoms. Therefore, if you add a certain amount of energy to an atom, you can excite one of the outer electrons into a higher energy state. However, since the energy states of the electron are quantized, only an exact energy match will promote the electron to the higher state.

Laser, being a highly stable nearly monochromatic source, became one of the most important tools in probing atomic structure from the moment of its invention in the 1960s. For our experiment you will use a low power diode laser (less than 15 mW). Diode lasers came on the scene in the late 80s, and since then have gained huge popularity because they're cheaper, require less power, and their output wavelengths are dependent on temperature and current in a controllable way. That is, the wavelength of the light produced can be adjusted by tuning either the temperature of the laser or the current being supplied to the laser.

The diode laser you will be using in the experiment is a very small and delicate device. The actual diode gain medium is less than one millimeter long and wide. If you were to remove it from its metal casing, it would look similar to a sedimentary stone (Figure 1). The top and the bottom layers are electrodes that are attached to the current supply. The inner layer is a small piece of cleaved crystal. It has been precisely cracked so that the ends can be used as laser cavity mirrors. One end of the crystal is coated with a highly reflective substance while the front is coated with a partially reflective substance. The diode laser we use has an adjustable external laser cavity, which allows us to tune the output wavelength of the laser. The divergent output beam from the diode gain medium is collimated using a simple lens and directed toward a reflective grating (see Sect. III). The grating reflects part of the laser beam back into the gain medium and the rest out of the laser. The exact angle of the grating determines the wavelength that is fed back into the diode and amplified, while the distance between the grating and the diode determines the geometrical length of the external cavity. Very fine adjustments to the grating angle will allow you to quickly vary the wavelength of the outgoing light.

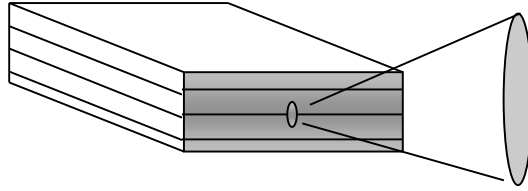


Figure 1: Diode Laser Gain Medium and Output Beam

The basic principle of absorption spectroscopy is that you can tell information about the target's energy levels by the wavelengths of light that it absorbs. By passing the beam through a Rubidium vapor cell and monitoring the power level of the transmitted beam, it is possible to detect absorption of light. When the frequency of the laser beam equals the frequency needed to drive a transition of an electron into an excited state, the atoms absorb the photons from the laser beam. Once an atom absorbs a photon, it decays almost instantaneously back to its ground state and emits a photon of the same frequency that it absorbs. Since the re-emission occurs in random directions, the energy of the scattered photons is lost from the original beam. Therefore, the intensity of the laser light passing through the cell drops along the beam path. Measuring the power of the transmitted light as a function of the laser frequency, we can identify the frequencies of strong absorption. The absorption frequencies times the Planck constant equal the energy levels of the Rubidium atoms in the cell.

A common limit on spectral resolution in this process is the Doppler broadening. This Doppler broadening is due to the motion of the Rubidium atoms themselves, which move with an average speed of about 300 m/s at room temperature. We measure the frequency of the laser beam in a stationary frame; however, the majority of rubidium atoms in the cell do not share this vantage point. Atoms moving toward the laser beam “see” an upshift in the frequency of the light. Since this experiment is conducted at room temperature and the average velocity of the moving atoms, $v \ll c$, the frequency shift can be described by:

For atoms moving towards the laser

$$\omega = \omega_l \frac{v}{c}, \quad (1)$$

For atoms moving away from the laser.

$$\omega = \omega_l \frac{v}{c}, \quad (2)$$

where Δ is the change in frequency from the laboratory frame, ν_l is the frequency in the laboratory frame, v is the velocity of the rubidium atom, and c is the speed of light.

Because of the distribution in molecular velocities there will also be a distribution of light frequencies (as viewed in the lab frame) that can be absorbed by the rubidium vapor, even for a single atomic transition. At thermal equilibrium, we can assume that the molecular velocities in the Rubidium vapor will follow a classical Maxwellian distribution, as shown in Figure 2.

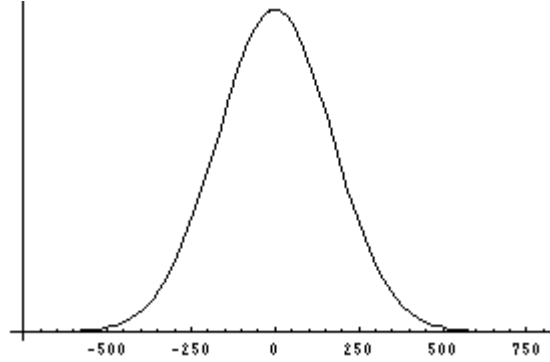


Figure 2: Maxwellian Distribution of Velocities: $n_i(v) = \frac{N_i}{v_m \sqrt{\pi}} e^{-(v/v_m)^2}$ at Temperature $T=298$ K for Rubidium Vapor, where $v_m = \sqrt{\frac{2kT}{m}}$, where v_m is the mean molecular velocity.

Note the width of the distribution is

$$v_D = 2\sqrt{2kT \ln(2)/m}. \quad (3)$$

Let's suppose that a stationary atom (with respect to the laser) will absorb light with frequency ν_0 . We wish to find the distribution of frequencies that atoms in the vapor will absorb at a non-zero temperature.

Combining the velocity distribution, Eq. (1), and Eq. (2), we find a frequency distribution that exactly mirrors the velocity distribution.

$$n_i(\nu) = \frac{N_i c / \nu_0}{v_m \sqrt{\pi}} e^{-(c/\nu m)(\nu/\nu_0 - \nu_0/\nu)^2} \quad (4)$$

If Doppler broadening is the primary source of uncertainty in the absorption spectrum, this will determine the overall spectral width of your observations. The full width at half the maximum value (FWHM) for Doppler broadening at temperature T , for atoms with mass m , is given by:

$$\Delta \nu_D = \frac{\nu_0}{c} \sqrt{\frac{8kT \ln 2}{m}}. \quad (5)$$

Saturated absorption spectroscopy can be used to overcome this spectral resolution limitation. The basic premise is to somehow select out only the stationary atoms to use in spectroscopy.

First, we'll try to understand the "saturated" part of this technique. Consider a collection of atoms in the gaseous state with ground state E_i and excited state E_k (See Figure 3). Before any light is passed through the vapor, almost all of the atoms are in the ground state. If we pass a relatively weak beam of light (call it the "probe" beam) through the gas at the resonance frequency of the E_i to E_k transition it will undergo normal absorption, governed by the Gaussian frequency distribution given by Eq (4). Now, suppose we pass an intense beam of light (call it the "pump" beam) through the gas at the resonance frequency of the E_i to E_k transition. The atoms will absorb this light, populating state E_k and depleting the population in E_i . If we now pass the probe beam through the gas, there will be fewer atoms to be excited than before (since they were removed from state E_i by the pump beam). Hence, there will be less absorption of the probe beam. In this case, the pump beam is said to have saturated the transition.

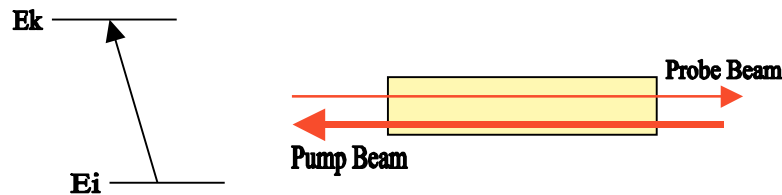


Figure 3: Transition between energy levels E_i and E_k . Pump and Probe beams passing through gas of atoms.

Now, consider counter-propagating pump and probe beams, both with a frequency that is slightly below ν_0 . For convenience, choose the probe beam to be traveling to the right. For an atom to interact with the probe beam, the frequency would have to be upshifted in its frame. Therefore the atom would have to be traveling toward the probe beam at some given speed (to the left). Now if that atom were to interact with the pump beam, the frequency would also need to be shifted up. Therefore the atom would have to be traveling toward the pump beam at some speed (to the right). A similar argument can be made for frequencies slightly above ν_0 . This means that at any given frequency in the laboratory frame, the two beams can only interact with atoms traveling in opposite directions but equal speeds. Therefore neither beam will be affected by the other's presence for frequencies other than ν_0 . At ν_0 both beams can interact with the same rubidium atoms, namely the atoms which do not move parallel to the beams. The pump beam will saturate the ν_0 transition, reducing the absorption coefficient of the probe beam. The sharp dip in the absorption spectrum (of the probe beam), for the $v = 0$ atoms, is referred to as a Lamb dip (See Figure 4).

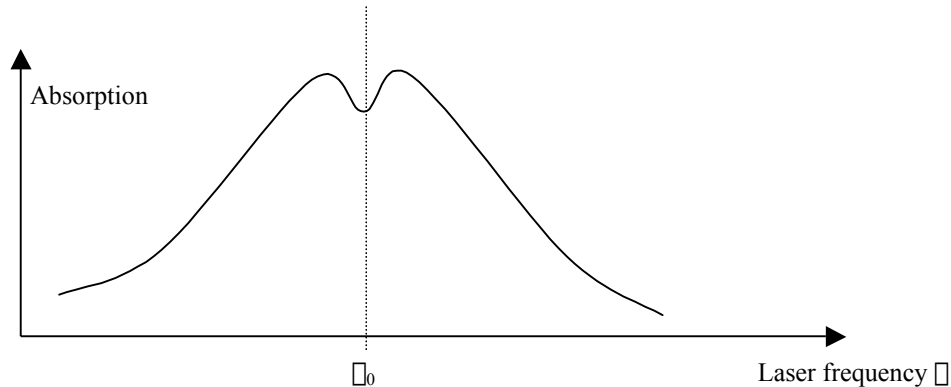


Figure 4: Lamb dip at the center $\nu = \nu_0$ of a Doppler-broadened absorption line (W. Demtröder, *Laser Spectroscopy*, pp. 486).

As seen in Figure 4, Lamb dips can be orders of magnitude narrower than the Doppler broadened absorption lines. The width of a Lamb dip is determined by several factors. First, there is an inherent “natural line width” because of the uncertainty principle. Secondly, collisions of rubidium atoms with the walls of the cell and other rubidium atoms broaden the Lamb dip. Thirdly, the spectral width of the laser is a finite quantity, and the absorption spectra will reflect the laser line width. All of these quantities can be estimated, or in the case of the laser, determined from laser specifications. So, for our laser the linewidth is 1.2 MHz, and the transition linewidth for Rb under our conditions is about 6 MHz.

The saturation absorption spectroscopy technique is useful because you can see the hyperfine splitting of Rubidium explicitly on the oscilloscope display. In order to better understand what you’ll see on the display, you should study Figure 10 in detail. There are several important facts not explicitly noted in Figure 10. First of all you should be aware of the notation used. The Russel-Saunders notation $^{2S+1}L_J$ is well known (see for example Griffith’s *Intro to Quantum Mechanics* eq. 5.34). The effect of the nuclear spin on atomic transitions is less commonly discussed in the introductory Quantum Mechanics courses. The spin of the nucleus (denoted by I , but do not confuse it with isospin which is not used in atomic physics) is added to the total spin J of the electron according to the usual angular momentum addition rules to produce a new quantum number, F , to describe the total spin of the atom. The nuclear spins of the two known isotopes of Rb are $I(^{85}\text{Rb})=5/2$ and $I(^{87}\text{Rb})=3/2$, and you should verify that when it is added to the total spin J of the outer electron, the obtained quantum number F takes on the values shown in Figure 10 for the $5S_{1/2}$ states and $5P_{3/2}$. This quantum number characterizes sublevels within the $5S_{1/2}$ and $5P_{3/2}$ states that would vanish if you neglected nuclear spin. These sublevels are the hyperfine structure of Rubidium. The laser used in this lab is tuned to a relatively narrow band around a wavelength of 780nm, the wavelength of

transition between the $5S_{1/2}$ and $5P_{3/2}$ states. The selection rule for F is $\Delta F = -1, 0, \text{ or } 1$. This implies that there are a total of 12 transitions from $5S_{1/2}$ to $5P_{3/2}$ for different values of F. If you look at the four pages of graphs near the end of this lab manual, you will see a print out of the oscilloscope display for the transitions from the four possible ground states (two for each isotope of Rubidium). Each graph has six peaks. Three are the actual peaks corresponding to the initial state you chose and three are the so-called cross-over peaks (which we discuss below). This information and the Figure 10 energy level diagram should greatly assist you in identifying the peaks that appear in the oscilloscope pattern.

By using a Michelson interferometer, you can obtain quantitative energy values for the hyperfine splitting of Rubidium. By using an oscilloscope, you will be able to superimpose the sinusoidal interference pattern from a Michelson interferometer onto the pattern derived from the saturation spectroscopy. The Michelson interferometer is used to detect shifts in the interference fringes produced by (in this case) a “scan” by the laser through a band about a GHz wide. The light used in the interferometer is taken from part of the laser beam that goes into the saturation spectroscopy (see figure 6). The equation for the Michelson is extremely simple: $\Delta L = (nc)/\Delta f$. Here ΔL is the total path difference of the two light beams, n is the number of fringe shifts, c is the speed of light, and Δf is the change in frequency. Rearranging, and setting n to 1, $c/\Delta L = \Delta f$. You should find the ΔL for the interferometer on the optical table (it will be helpful to know that the screwholes on the optical tables in the US are spaced by 1 inch). For value of $\Delta L = 6.3854 \text{ m}$ the above formula gives, to two significant figures, $\Delta f = 47 \text{ MHz}$. This is the frequency difference between two adjacent maxima in the Michelson *intensity* (not E-field) pattern. This is the same as half a cycle on Michelson E-field oscilloscope display. Now that you have a Δf value, you can use the quantum hypothesis to convert Δf to a change in energy: $\Delta E = h\Delta f$ so a Δf of 47 MHz would correspond to an energy difference of $\Delta E = 194 \text{ neV}$ (nano electron volts). Using this interferometer energy scale as a standard, you will be able to obtain approximate energy values for the hyperfine splitting in Rubidium by comparison.

Before we proceed to the procedure, we should be aware of a couple other spectral features that we will see. We will be working with atoms in which two transitions share a common initial state. Consider once again counter-propagating pump and probe light (as in Figure 3), but this time both have a frequency of $\omega = (\omega_1 + \omega_2)/2$ (see Figure 5). Now, the pump light will interact with atoms moving to the right which are Doppler shifted into resonance with transition 1. It is these same atoms that are Doppler shifted into resonance with the probe beam, which is propagating to the left. Because both the pump and probe beams interact with the same atoms, we see a decrease in absorption of the probe light. This shows up as a crossover peak in the saturation spectrum. If there are more than two levels into which atoms may be excited from the same ground state, each pair of such level generates a cross-over peak half way between the “real” Lamb dips.

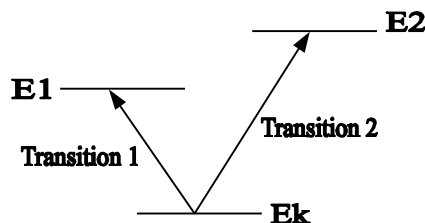


Figure 5. Two transitions sharing a common initial state will produce crossover resonance in the saturated absorption spectrum.

Using the saturated absorption technique, we can identify the zero-velocity transition energy, and we can measure the natural line shape of that transition with the precision, limited only by the laser we are using. In addition, as we will see in subsequent labs, we will use saturated absorption spectroscopy to lock the frequency of our diode lasers.

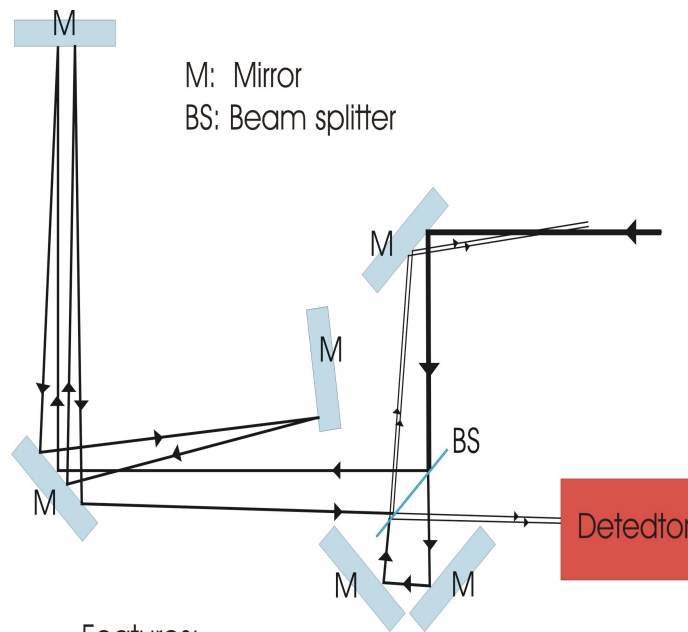
Aligning the Interferometer:

In order to make use of the Michelson as a tool to calibrate the frequency axis when making measurements, as described above, you need to make sure that the interferometer is aligned correctly. A slight misalignment will render the interferometer useless. If there is no clear, sinusoidal display on the second channel of the oscilloscope, the Michelson interferometer is probably out of alignment. To make sure you really are seeing the interference pattern, you may want to place a piece of paper between two of the mirrors in the interferometer to see if what you think the pattern is disappears. If it does you correctly identified the pattern and no realignment is necessary. If nothing changes, the interferometer needs to be realigned. It is a fairly straightforward task to align the interferometer if you've done it once and know what to look for. Even if you have no prior experience, it should still be possible to align the interferometer with a minimum of help from your lab instructor by following these steps.

- 1) **Use the function generator to put the laser in a slowly scanning mode of about 1 scan per second, scan width of about 16 Hz.**
- 2) **Put a note card or piece of paper over the detection window on the photo-detector. This will allow you to see the interference pattern on the sheet. The goal, of course, is to get the interference pattern right over the window. That way, when the pattern looks good on the paper, all you will have to do is to remove the paper and the pattern will register. You may have to turn off the lights to see anything.**
- 3) **Hopefully, the misalignment won't be too bad and you will be able to see some sort of pattern on the paper. If you see a pattern, then the problem is probably that the interference pattern is too small for photo detector to register. If this is the case then all you will probably have to do is play with the beam splitter to make the distance between interference fringes larger. You should see a fringe shift simply by changing the beam splitter's fine adjustment controls. Go slowly. A little adjustment will result in a large**

fringe shift if the interferometer is just a little out of alignment. (Two little knobs about a centimeter in diameter. One for vertical and one for horizontal adjustment.)

- 4) If you can get the pattern such that the entire spot periodically disappears and then reappears on the paper, you have made the two beams on the interferometer perfectly parallel. This is the ideal case and it is almost impossible to achieve perfectly. You will know if your pattern is good enough if the photo-detector registers a nice, smooth, sinusoidal curve on the scope
- 5) If the pattern is more than just a little off, that is if you don't see any interference, realignment is a lot harder. If you can at least see two distinct spots on your sheet you don't have to worry too much. Firmer adjustment of the beam splitter will probably be enough to make the two spots merge into an interference pattern. This may take awhile. Continuously switch between using the vertical and horizontal adjustment controls. If no or only one spot is visible, one of the mirrors probably got bumped somewhere along the line. You have to find which one. The only way to do this is to check each mirror individually using a piece of paper. (See Figure 6) You should start at the beginning and work your way forward, making sure that light is coming off of each mirror. This part of the procedure is useful in realigning any optics experiment. Once you find where the chain is broken, put your paper back in front of the detector and slowly, slowly turn the mirror until you see a pattern or two distinct spots. From here you can use the beam splitter.
- 6) If even this fails, more the one mirror is probably off and you will need assistance from your lab instructor.



Features:

Increased path length difference due to a "double-bounce" in the long arm.

Return beams do NOT back track the incident beam from the laser diode. As a result there is no feedback.

FIGURE 6: THE MICHELSON INTERFEROMETER

III. PROCEDURE

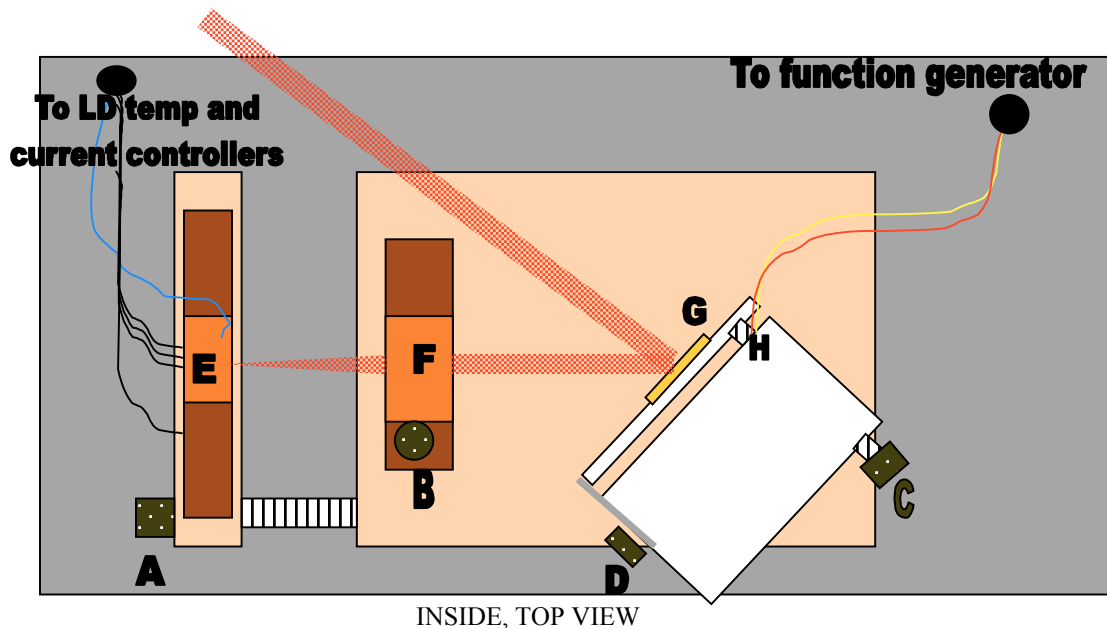
Warning: All optical surfaces (mirrors, gratings, etc.) in this lab could be permanently damaged by touching them; grease from fingers is particularly detrimental. Please use caution when working with the optics.

In order to perform any experiments involving lasers, you must first make sure the laser is properly aligned. The diode laser used in this experiment has an external cavity and a myriad of adjustable parts. The first thing you will need to do is take proper safety precautions to protect you and the laser. The free-running wavelength of the current laser is 782 nm which is far red / infrared light and barely visible to the human eye. At low power levels, it will not be visible even in near complete darkness. **This means it is essential that you are aware of the beam path at all times and under no circumstances should you**

look into the beam path; this may result in permanent damage to your eye and possibly blindness. You should also make sure that no part of the beam is allowed to escape your immediate work area.

The laser itself is a delicate piece of equipment. Like all diode lasers, it is extremely sensitive to charge and current, so precautions must be taken to ensure that it is exposed to no sharp current “spikes.” The main cause of current spikes in the laboratory setting is static discharge and power backlashes from nearby equipment. You should wear a static wrist guard at all times when touching any component of the laser diode package. When you arrive in lab, the laser should be already close to the desired wavelength. It will not be necessary to make adjustments inside of the laser package itself. Nevertheless, it would be good to: **(1) Familiarize yourself with the laser diode package and understand how it works (Figure 6).** Make sure you are properly grounded and then GENTLY open the cover on the laser diode box (bumps to the system can jeopardize your ability to finish this lab on time!). Do not make any adjustments before consulting your professor or lab instructor. You should also examine the manuals for the laser temperature and current controllers before beginning this lab.

The light from the diode is highly divergent. The beam is collimated using Adjustments **A** and **B** (Figure 6). (By adjusting the distance of the laser diode from the collimation lens) You may want to verify that the beam is in fact stable over a range of several meters before you proceed. If it is not, consult your lab instructor.



- A:** Laser diode horizontal position control
- B:** Lens Vertical Adjustment
- C:** Grating (horizontal) Tilt Control
- D:** Grating (vertical) Tilt Lock
- E:** Laser Diode and Thermo-Electric cooler
- F:** Collimation Lens
- G:** Grating
- H:** Piezo-Electric grating angle control

Figure 7: The Laser Diode Package

By itself, the laser diode can lase at many frequencies between around 780 and 785nm, but we can force it to lase at a desired frequency using an external cavity created by the grating, (**G** in Figure 7). The reflection from the grating is sent back into the laser diode, steered by using Adjustments **C** and **D**. If the grating is then tilted by a very small amount (using Adjustment **C**), the laser cavity changes, forcing the laser to lase at different frequencies. The frequency output is highly sensitive to even the tiniest adjustments of the grating tilt. You can tune laser diode by hand with a precision of about 0.1 nm. Adjusting the grating by hand is the roughest method of tuning the laser and should only be used when you know that the laser is far off from the desired wavelength (it should not be necessary to do this in this lab)! Once we've got the laser close to the right frequency, we will use a piezo-electric connected to Adjustment **C** to move the grating by small amounts, tuning the wavelength slightly (with precision of about .0001 nm).

The frequency output of the laser is also highly sensitive to temperature and the current that runs through the diode. To avoid frequency drifts due to temperature and / or current changes, we have connected a Laser Diode Temperature and Current Controller to the laser diode.

Note: Before making any adjustments to the temperature or current settings make a note of their present settings. We've found that the laser diodes we use lase well with temperature and current settings around 94.9 mA with the temperature controller reading 12.85 k Ω .

The temperature controller displays the resistance of a thermistor, which is a temperature-sensitive resistor, mounted next to the laser diode. The conversion chart between temperature and resistance is given in the manual. The cooling of the laser diode holder, which contains both the laser diode and the thermistor, is accomplished via a Peltier element placed underneath the holder. The Peltier element acts as a heat pump that moves thermal energy from the diode holder to a much larger copper mounting block. The mounting block represents a thermal reservoir, into which the Peltier element discharges the thermal energy removed from the diode holder plus the electric energy used to operate the heat pump. The steady-state temperature of the laser diode can be varied via the cooling power of the Peltier element, which increases with the current passed through it. Using the temperature control unit, you can tune the laser wavelength to within about .01nm of the desired wavelength; this is the second coarsest adjustment. The output wavelength drops by approximately _ nm for each degree Celsius the laser is cooled.

Adjusting the laser current should allow you to tune within about .001nm of the desired wavelength. You will complete the tuning of the laser after you have set-up the rest of the saturation spectroscopy apparatus.

All laser devices experience a threshold phenomenon. If we drop the current to the laser below a threshold value it will not lase. The manufacturer lists this threshold current as 25mA.

(2) You should adjust the current setting to find the threshold current. Compare this to the manufacturer's setting.

(3) Return the current control to its original setting.

We now are ready to set up our system for saturation spectroscopy. A glass tube containing Rb gas has been provided.

(4) Align the Rb cell, laser and optics as suggested in Figure 8.

After Beam Splitter 2, you will have two reflected beams, both of which need to pass through the Rb cell. One of the beams (the lower beam in Figure 8) will be used to obtain the normal, Doppler profile. The upper, reflected beam will probe the beam. The beam transmitted through Beam Splitter 2 will be the pump beam and will be overlapped with the probe beam in the Rb cell.

(5) It will be difficult to see the beam. You will want to turn off the lights in the lab. In addition, you will want to use a white card, which will fluoresce when hit by the beam. This will make alignment easier.

(6) Use an IR viewer (or set up the CCD camera) to view the Rb cell. This will allow you to see the fluorescence of the Rb molecules when the beam passes through the cell on resonance.

(7) Turn on the function generator. Make sure it is connected to the laser diode grating via the main output. Take it off of scanning mode (pull out the DC offset dial). Using the voltage offset, you can scan through a small range of frequencies. Do this while examining the cell for fluorescence.

(8) If you do not see fluorescence in the cell, make small adjustments in the current going to the laser, followed by adjusting the voltage offset until you see fluorescence. If you still do not see fluorescence, consult your lab instructor.

Ultimately, you will want to continue with steps (7) and (8) above until you are at a current setting which allows you to see 3 or 4 lines while adjusting the voltage offset (that is: you should see fluorescence at 3 or 4 different frequencies, corresponding to different transitions).

After the beams have been lined up in the cell,

(9) Use mirrors, M3 and M4 to steer each of the beams onto one of the photodiodes located on the photo-detector provided. The photodiode marked “reference” is designated for the unsaturated beam. The photodiode marked “signal” is designated for the saturated beam.

This photo-detector will generate an output signal that is proportional to a weighted difference between the light powers impinging on the two photodiodes.

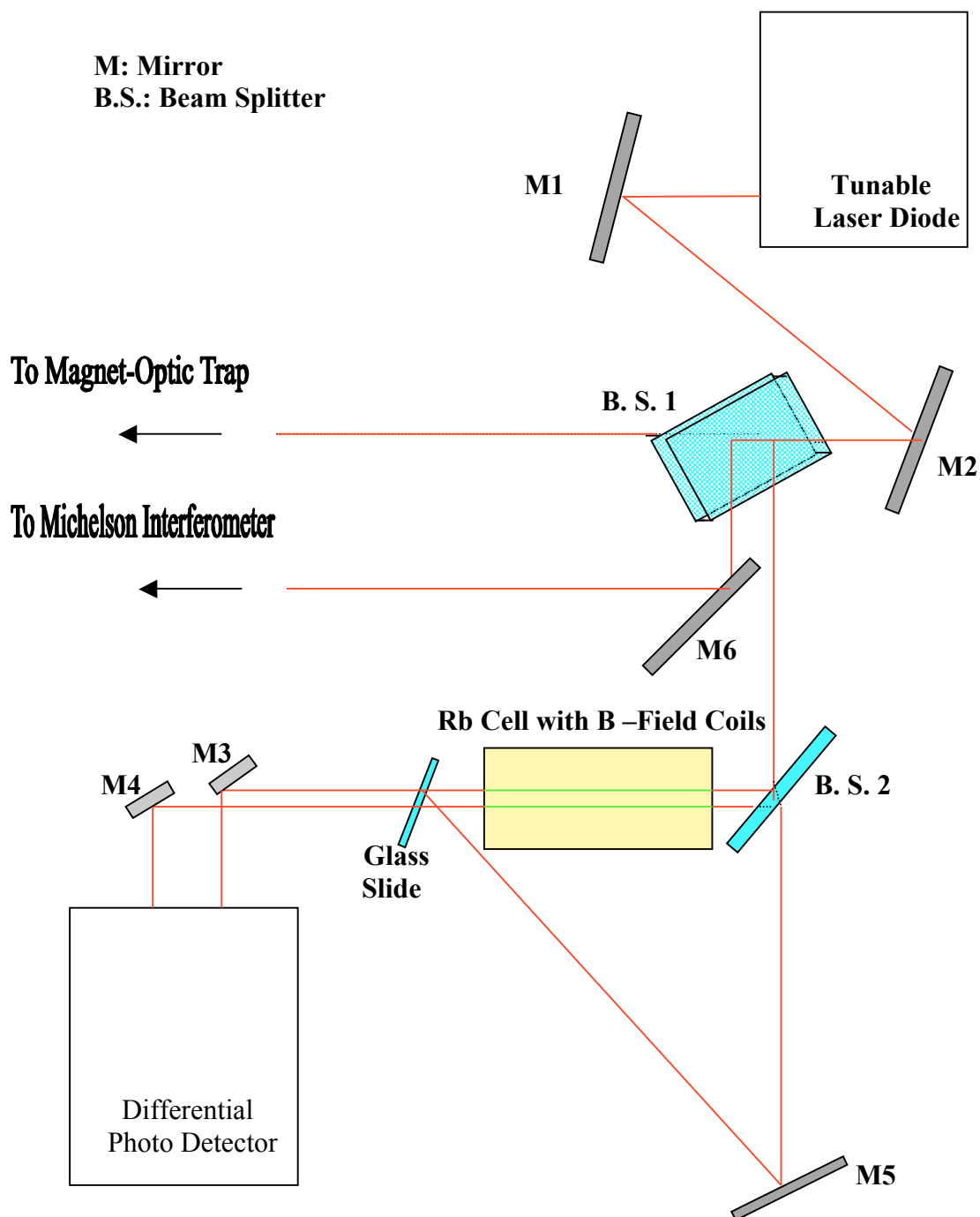


Figure 8. Saturation Spectroscopy Set-Up.

In order to obtain any kind of spectrum out of this exercise, you will need to

(10) Turn the function generator back on to a scanning mode. Use a saw-tooth line shape with a frequency of around 50 Hz.

Now,

(11) Connect the function generator's pulse output to the ext. triggering input of the oscilloscope. Connect the output of the differential photo-detector to one of the oscilloscope's input channels.

You will want to retain a record of the spectrum you see in each of the following steps.

To see the Doppler-broadened spectrum alone,

(12) Block the signal beam.

To see the Doppler broadened spectrum with Lamb dips,

(13) Block the reference beam.

To see the difference spectrum,

(14) Unblock both beams and adjust the gain of the photo-detector (using the dial on the photo-detector box) until the Doppler background is gone.

If you were able to locate what you believe to be a saturation spectrum, it's time for analysis. The Rb cell provided contains both ^{85}Rb and ^{87}Rb isotopes. The relevant transitions lie between the $5S\ 1/2$ and $5P\ 3/2$ in both isotopes.

(15) Use the energy level diagram below (Figure 10) to try and identify the peaks you witnessed in step (16). Compare quantitatively the $5S$ _ hyperfine splitting of ^{85}Rb and ^{87}Rb and see if you can explain their difference.

Now it is time to make use of the Michelson to estimate the energy value of the two isotope's hyperfine splitting. The relative spacing of the peaks should help you in the identification. To assist you, a sample spectrum is given in Figure 10, with the peaks associated with ^{85}Rb and ^{87}Rb indicated. This should serve well for as a standard for comparison to the frequency estimates you make using the Michelson interferometer. In addition, one transition is identified. Be wary of crossover peaks that do not correspond to an atomic transition. If you see a peak, which lays exactly halfway between two others, it's probably a crossover resonance.

(17) Using the frequency difference between two adjacent intensity maxima in the interferometer pattern, (47Mhz) estimate the energy value of the hyperfine splitting of ^{85}Rb and ^{87}Rb .

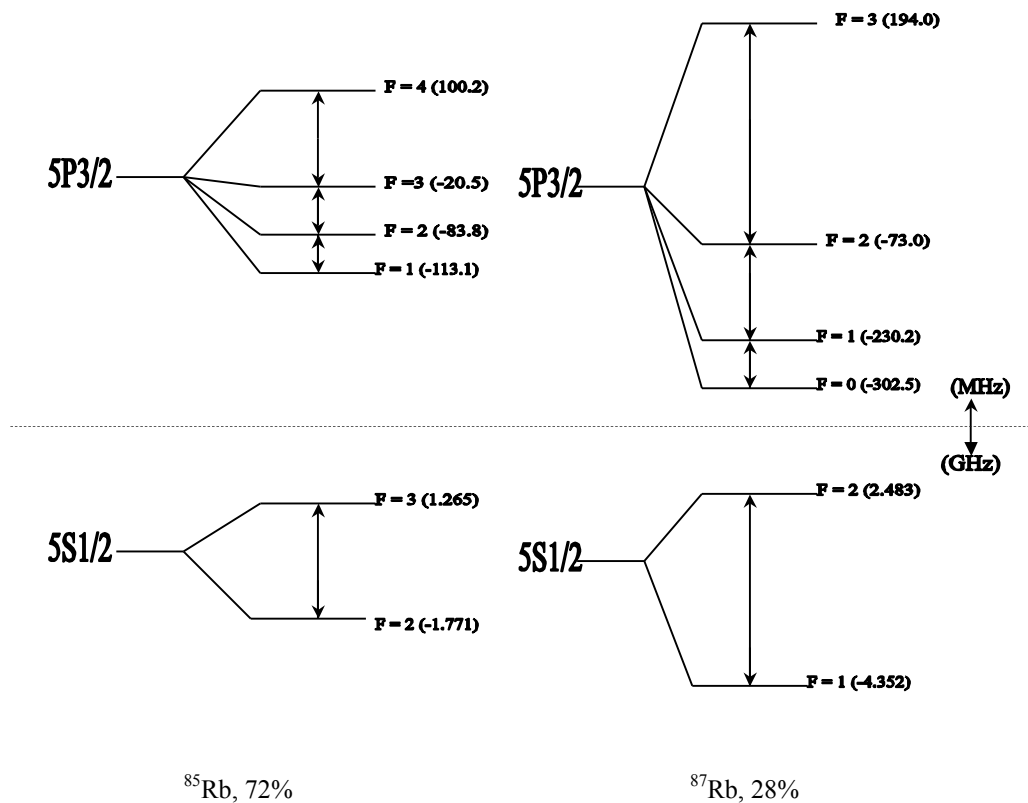
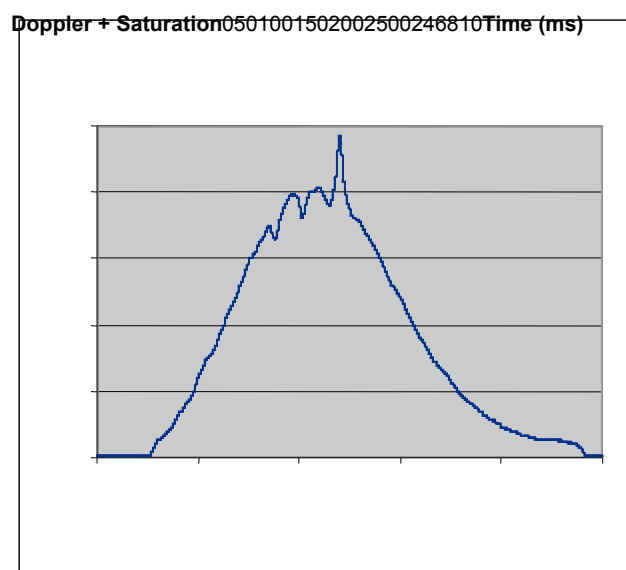
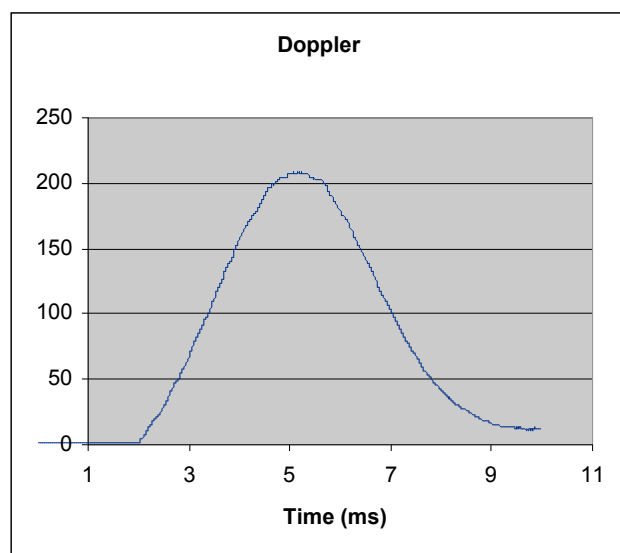
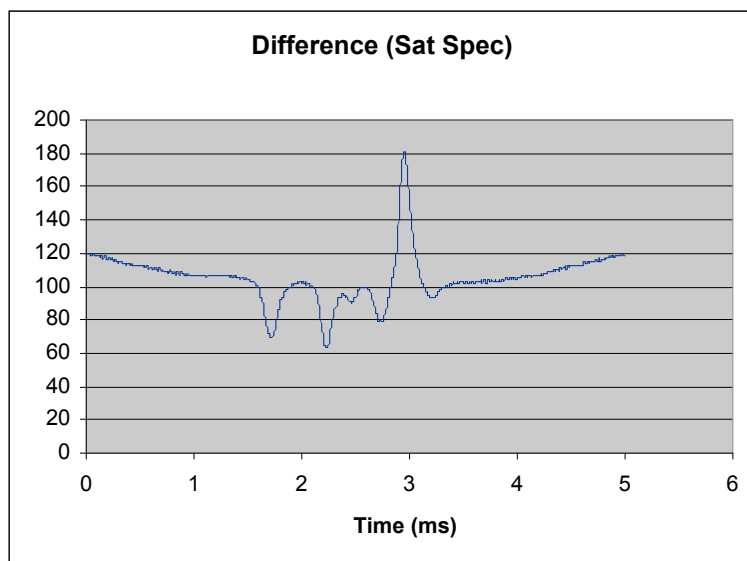


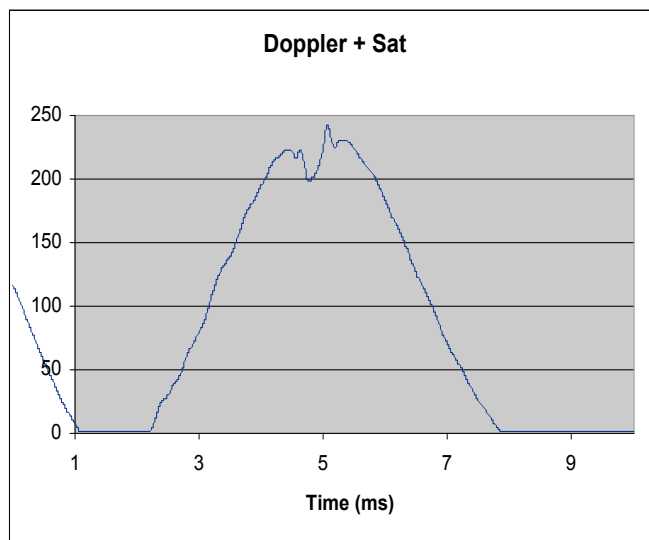
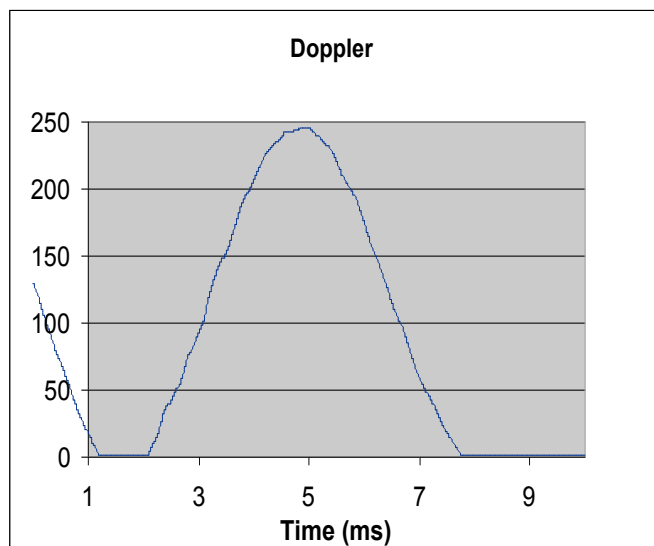
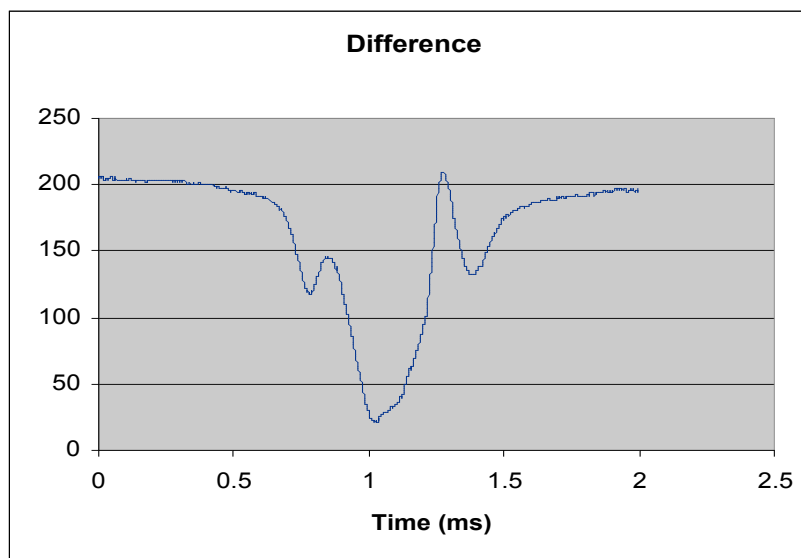
Figure 10. Energy Level Diagrams for ^{85}Rb and ^{87}Rb showing the transitions that are relevant to this lab.

Samples of Doppler broadened and Doppler Free Spectra

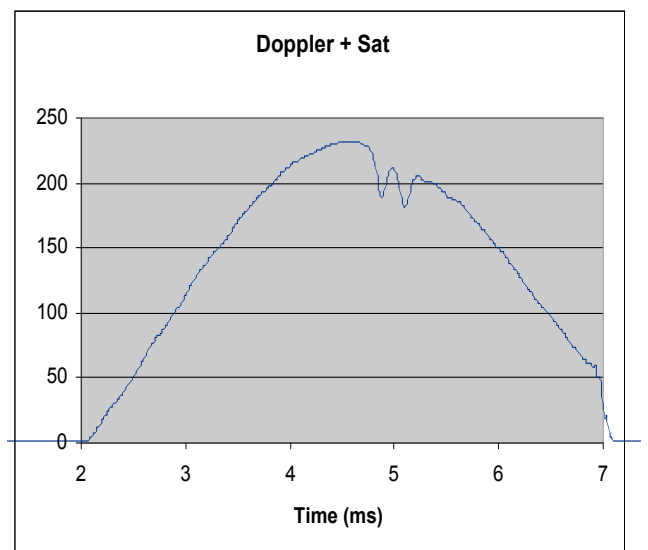
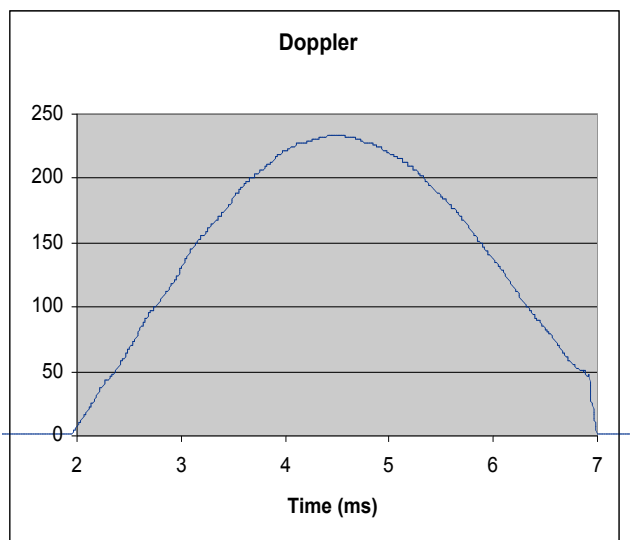
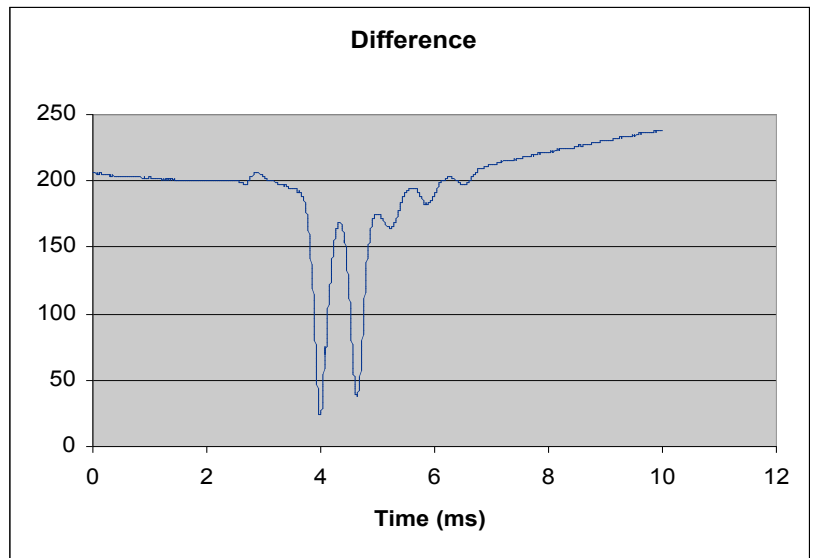
^{87}Rb
 $F=1 \rightarrow F'$



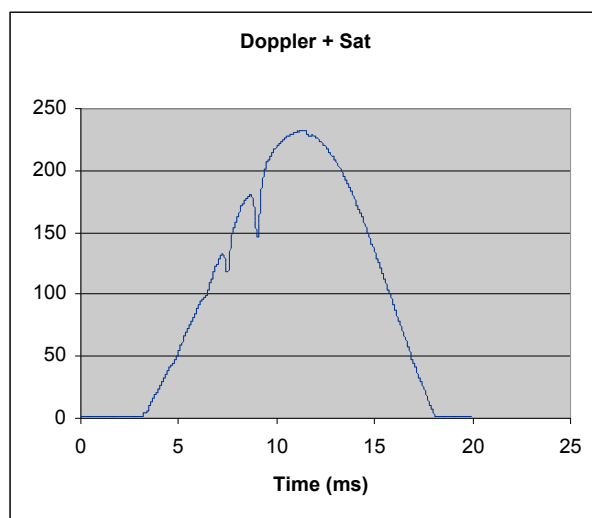
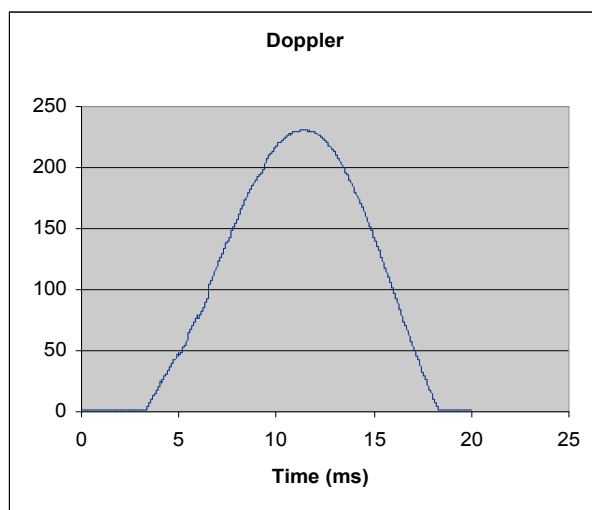
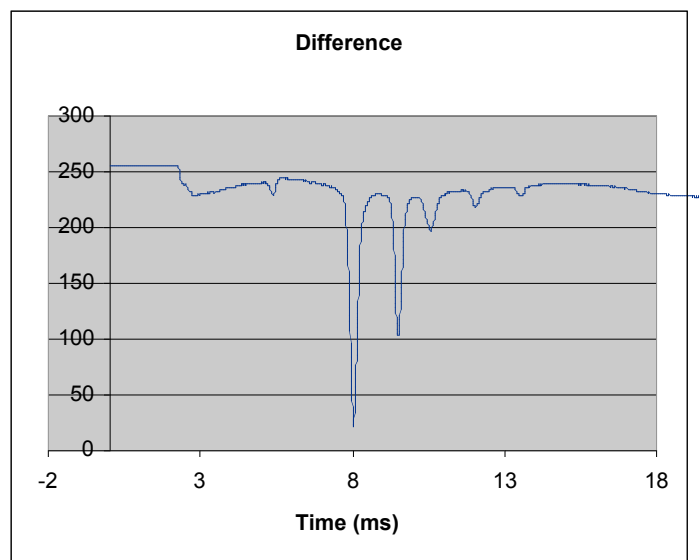
^{85}Rb
 $F=2 \rightarrow F'$



^{85}Rb
 $F=3 \rightarrow F'$



^{87}Rb
 $F=2 \rightarrow F'$



IV. DOWNLOADING DATA FROM THE OSCILLOSCOPE

After you obtain a spectrum, you can save it for later analysis. In order to do this you need to download the waveforms from the scope. You will need a scope with a GPIB card and a computer with Lab VIEW on it. First you need to set the address on the scope. Press the *Print/Utility* button, then go to *I/O Menu* and then you can set the address pressing *InstAddr*, the standard address for the scope is 7.

Once the scope is connected to the computer, open Lab VIEW, which is in the programs directory. Select open VI, then open the Trap.vi program, which is in the Atom Trap folder. This program will download what is on the screen of the scope, and save it to a text file. First turn the *Save_button* OFF, set the *Instrument Address* to 7. You can choose how many points to download, 500 is usually enough. With the *Averaging* switch OFF, click on the RUN button (the white arrow on the upper left corner). You should now see the same waveform as you see in the scope. Note that after you run the program the Scope will be in Stop, push the *Run/Stop* button on the scope to go back to Run mode.

You can also average over many waveforms to reduce the noise in the data. Turn *Averaging* ON and select the number of waveforms you want to average over. Once you have the waveform that you want, turn *Save* ON and run the program again. The program will take new data every time it runs, and the waveforms that are not saved will be lost. It saves the waveforms in a text file with a time axis and an amplitude (intensity) axis. You can view the data using **Excel**. When you open the data in Excel, the Amplitude data will be on the same column below the Time axis. If you want to plot the data you will need to cut and paste the Amplitude data onto another column.