Diode Laser Spectroscopy Workshop Handout

BFY II University of Delaware July 22-24 2015

We will be using Diode Laser Spectroscopy to explore the energy levels of atomic rubidium vapor. We will be using our laser to excite the $5S_{1/2}$ to $5P_{3/2}$ transition, which requires laser light of wavelength approximately 780.2 nm. Light photons can be variously described in terms of wavelength, frequency and electron-volts. For these experiments, we will work in frequency units. In order to be able to appreciate the relative magnitude of the energy differences being studied, we'll keep them all in GHz! NOW LET'S PLAY.

Controlling the frequency of the laser: While the basic frequency range of a laser is determined by the semiconductor used to make it, the 'exact' lasing frequency can be manipulated by a hierarchy of variables: laser temperature, current, grating feedback into the laser.

i. The biggest influence is temperature and TeachSpin sets that at the factory. Because we DO NOT want students to change this by accident, the temperature control for the laser head is on the back of the electronics box.

ii. Current through the diode both produces the brightness of the laser and slightly increases its temperature above the 'set-point'. While more current makes the light brighter, the temperature rise causes a slight drop in the frequency at which it lases .

iii. A diffraction grating can create optical feedback into the laser to tweak the wavelength. By using a piezoelectric element to tilt our grating back and forth, we will 'sweep' the frequency over a small range, about 10 GHz for our ~ 384,000 GHz laser.

To study energy level transitions, we send laser light through a cell containing rubidium vapor and use detectors on the other side to observe the transmitted light as the frequency is varied. Light at a frequency that matches a transition energy will be absorbed and we will see a change in transmission.

A quick look at the control panel for the electronics shows how we go about controlling the frequency and detecting, quantitatively, what happens to the light as we adjust our variables. The Current and Cell Temperature modules let us set those parameters. The temperature of the cell determines how much solid rubidium becomes atomic vapor that is able to interact with the light.

The ramp generator creates the changing voltage which powers the Piezo controller to vary the angle of the grating and thus 'sweep' the frequency of the laser. When the laser light reaches a resonant frequency, photons are absorbed by the rubidium atoms, decreasing the brightness of the transmitted light. The detector panel provides power for the detectors and offers extra signal manipulation.

1. **See how it looks when the diode begins to 'lase'.**
   a. Set up a white card in the path of the beam just after it comes out of the laser and aim the TV camera at it. Our eyes cannot see the spot created, but the camera can.
   b. *Slowly increase the laser current and watch what happens to the spot on the card. Can you tell when the LED becomes a laser?*

2. **Use the viewing card to follow the path of the laser light** reflected by the beam splitter which is deflected through the cell and into the two detectors. How does the fact we are using a wedge beam splitter explain both the fact there are two beams and that they are diverging? (NOTE: the portion of the beam transmitted through the beam splitter has been blocked. We'll follow that path later.

3. **Look at the connections between the oscilloscope and the control panel**.
   a. The scope is triggering on a rising signal from the ramp generator, which is generating a triangle wave.
   b. Channel 1 is showing the voltage from the ramp generator and thus shows the time variation of the angle of the grating, which in turn linearly controls the frequency of the laser.
   c. Channel 2 is connected to the Monitor on the Detector Panel. The Balance control on the panel allows us to send the signal from either the left or right detector (or some combination) to the oscilloscope.
   d. *With a low current setting, use the Balance control to vary the contribution from the two detectors. (You may need to tweak the Ch 2 sensitivity). What do you notice?*

4. **Create fluorescence**
   a. *Put the glass neutral density filter in front of the laser beam*. This means we can use larger currents, which we need to get into the resonance/absorption range, without saturating the detectors.
   b. *Set the detector* for the right side detector only and *Aim the camera* into the cell
   c. *Connect the ramp generator to the current module* so that the current will have a sweep in time with the grating. Set the current sweep modulation to about 0.6. (For reasons we won't discuss, this creates cleaner tuning.)
   Important note: The 'ramp' circuit is designed so that the current and grating changes work together to enhance the effect on the frequency. As the current increases, although the laser gets brighter, the actual light frequency drops and vice-versa. Because the brightness and ramp voltage change in the same direction, on the downward stroke of the ramp generator, the current is decreasing and the frequency of the laser light is increasing. Therefore, we can use the time scale of the falling portion of the 'scope traces as a rising frequency axis.
   d. *Slowly increase the current watching both the detector trace and the TV monitor. What happens and why?*

5. **Interpret the oscilloscope trace.**
   a. *What is the source of the four 'dips' in the in the oscilloscope trace of detector intensity?*
   b. *How are they related to the energy transitions of the rubidium?*
   c. *What does the shape of the features have to do with Doppler broadening?*
   d. *Look carefully at the energy level diagrams – how many transitions should actually be involved? Remember an F=2 can go to F'=1, F'=2 or F'=3)*
   e. *Why don't we 'see' them? (HINT: the frequency difference between the first and last of the four dips is on the order of 384,000 GHz, the largest fine structure difference is about 0.3 GHz!)*

6. **Use Saturated Absorption to reveal the missing features**.
   a. *What is the role of the pump beam?**
   b. *What should happen when we unblock it?*

UNBLOCK THE PUMP – cheering is encouraged.

7. **Use the view card, to follow the beam that passed through the beam splitter around its path**. You will see that it is sent into a 50/50 beam splitter which aims part of the light back through the cell exactly co-linear to the probe beam. Take a look at the oscilloscope trace – admire the spikes

8. **Take a moment to go back and change the BALANCE on the Detector Monitor Module**
   a. *Turn the signal from the right side detector to zero and bring the left detector to about half.*
   b. *What do you notice about the sense of the signal and its shape?*
   c. *How can we use this behavior to help us see the transition signals more clearly?*

9. **Enhancing the view**
   a. Bring the center of the lowest frequency Doppler dip to the center of the screen
   b. Change the time sweep of the 'scope until you can see the features clearly.
   c. Use the BALANCE feature to adjust the signal from the left detector until you see the saturated absorption peaks! (Remember, the signal from the second detector – the inverted one, has not been disturbed by the pump beam.)
   d. Now you can just play. Gently tweak the adjustment screws on the steering mirrors to be sure the peaks are as high as you can get them. Higher peaks mean more perfect beam overlap.

8. **With lots and lots more time**, we could set up either an unequal arm Michelson spectrometer or the Fabry-Perot cavity to calibrate the optical frequency sweep and then find the actual transition frequency differences.

*** A Short Discourse on How Saturated Absorption Works.**

The absorption frequency for the *probe beam*, is significantly Doppler broadened by the random velocities of the rubidium atoms. Atoms moving toward the beam absorb photons when the beam frequency is below that of the transition energy frequency. Atoms moving away from the beam absorb when the frequency is above the transition energy. Only atoms standing still or moving perfectly perpendicular to the probe beam absorb at the frequency we are looking for. With widely separated transitions from $S_{1/2}$ to $P_{3/2}$ we would have no problem. The key spots would be the middle of each Doppler dip. But our frequencies of interest are so close that their Doppler dips overlap. We need a way to isolate them.

What if we created a *pump* beam which always had exactly the same frequency as our probe beam but moving in the opposite direction? When the laser frequency exactly matched a transition frequency, any atom either standing still, or moving perpendicular to the two beams, could absorb photons from either beam. The beams would compete for absorbent atoms. For all other velocities, the Doppler Effect would work oppositely. When the laser frequency was below transition frequency, atoms moving toward the probe beam would still be able to absorb only probe beam photons. To those atoms, these pump beam photons would seem even lower in frequency than they actually were. No competition. The situation is similar when the actual laser frequency is above the transition frequency. Atoms that were moving *away* from the probe beam and could absorb probe beam photons would be moving *toward* the pump beam, putting pump beam photons even more out of range.

ONLY when the diode is lasing at the exact transition frequency is there a set of atoms (the ones with no velocity along the beam path) that can absorb from either the probe or pump beam; *it is only at this frequency that there is competition*. This means that for this frequency the number of atoms able to absorb our probe beam will be decreased – which means, of course, that the amount of *light reaching the detector should INCREASE*. In other words, we should get a spike in the Doppler curve right at the absorbent frequency!

Rubidium Atomic Energy Level Diagrams

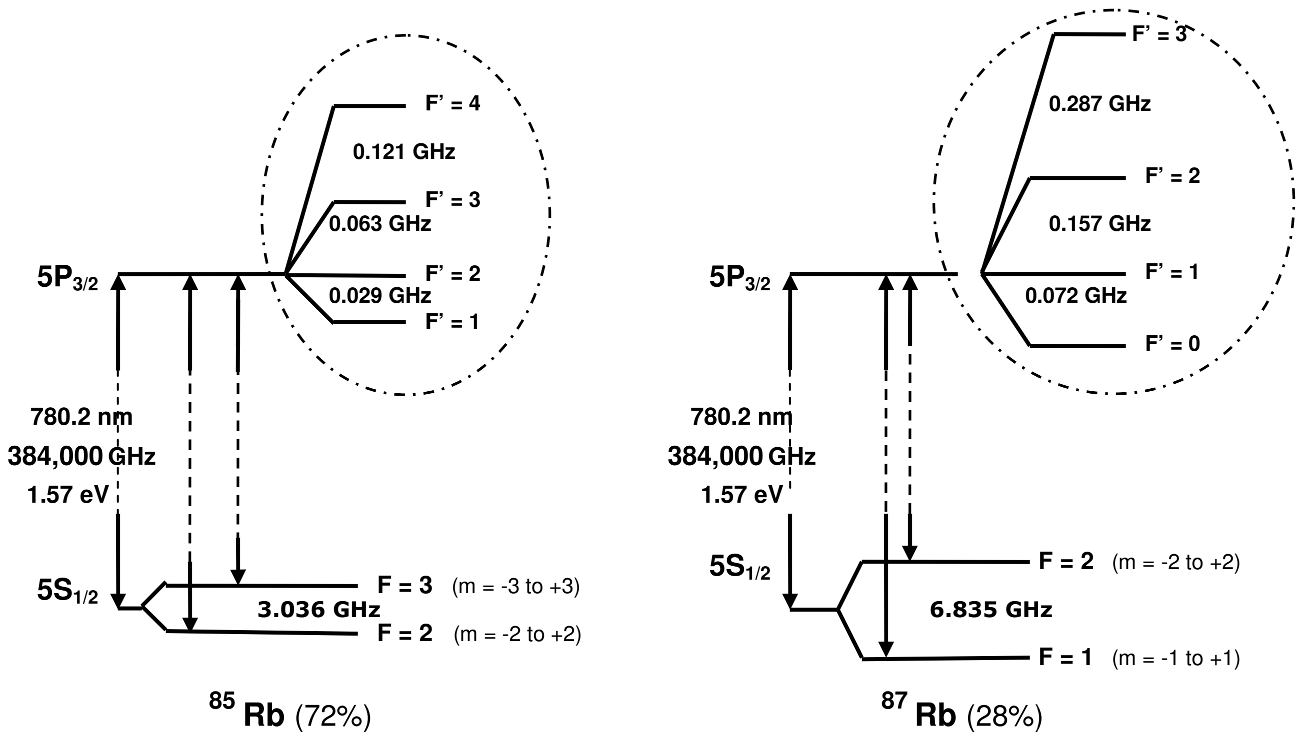

Figure 1: Energy level diagrams with some relative differences attempted

Transmitted Light vs. Laser Frequency

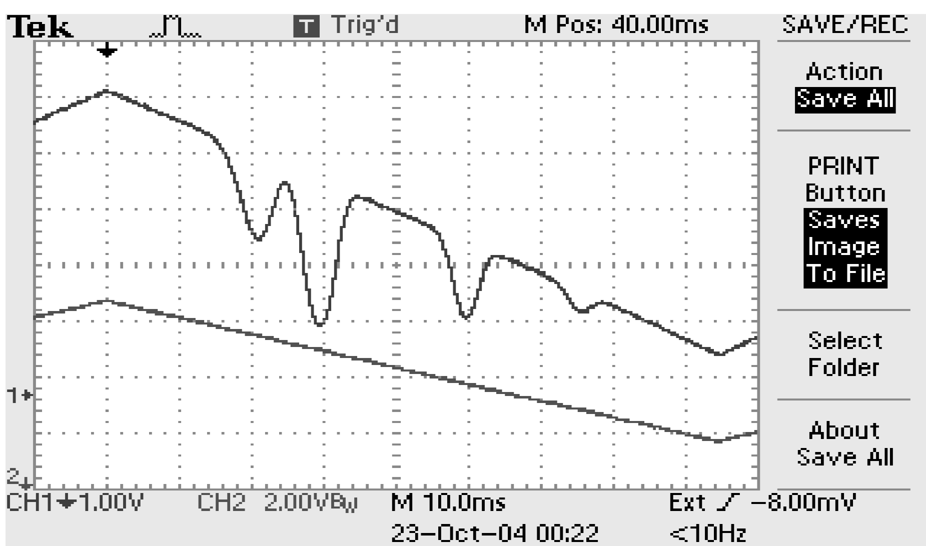

Figure 2: Transitions Left to Right: 87 F=2 85 F=3 85 F=2 87 F=1

Lower Trace: Sawtooth ramp voltage which is creating a "sweep" of both the laser current and the grating angle. This, in turn, creates the change in the laser frequency.
Falling sawtooth corresponds to increasing frequency.

Upper Trace: Transmitted light received by the detector. In the section of the trace shown, **frequency increases with time**.

Optical Plan for Saturated Absorption

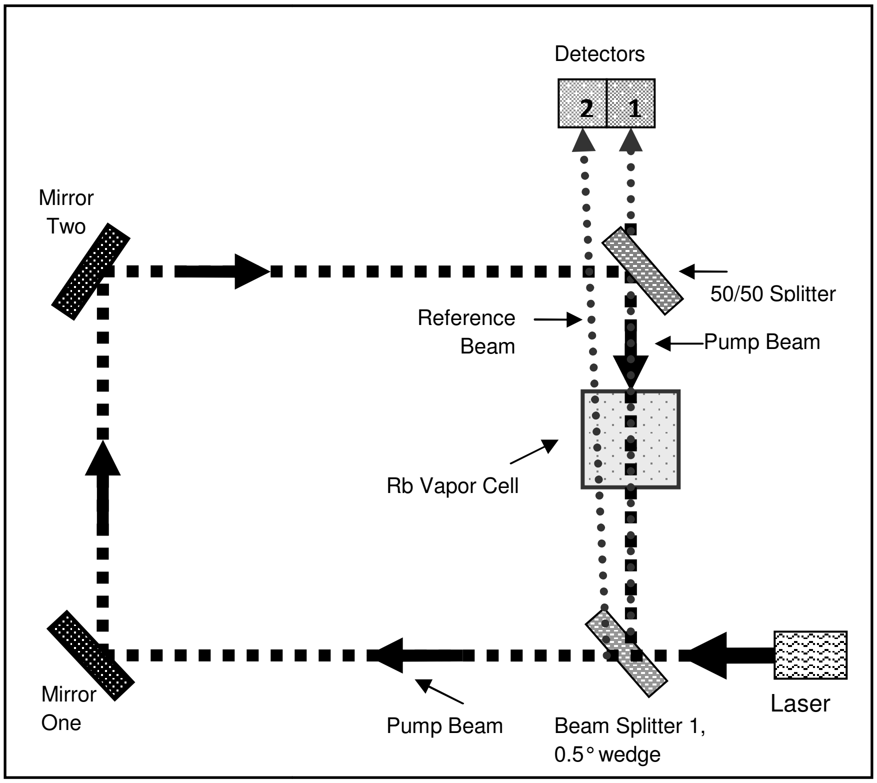

Figure 3: A schematic diagram of an optical layout suitable for performing diode laser pump-probe experiments in rubidium vapor.

Transmitted Light vs. Laser Frequency with Pump Beam On

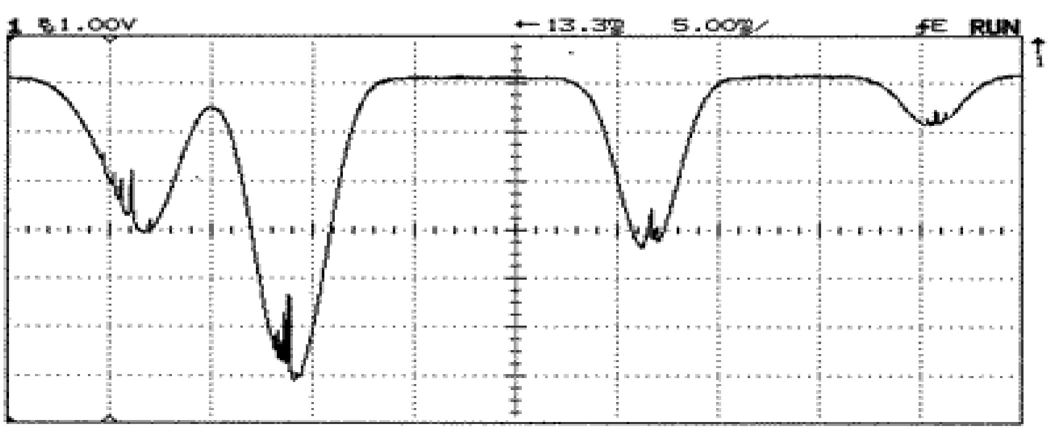

Figure 4: Trace showing features that appear when pump beam is introduced. In the section of the trace shown, frequency increases with time. For this trace, only the grating angle is being changed. The laser current is constant (not ramped), as indicated by the flat base line.