

Saturated Absorption Spectroscopy Lab

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I. INTRODUCTION

This lab is an introduction to saturated absorption spectroscopy. We will be observing the “D2 transition” in Rubidium vapor. This is the transition between the $5S_{1/2}$ ground state and the upper fine structure component $5P_{3/2}$ of the first excited state.

The rubidium nucleus will alter the spectrum we will be observing in two ways. First, the nuclear spin couples with the electron spin to split the ground and excited states. Second, rubidium consists naturally of two isotopes, Rb-85 and Rb-87. This will cause two separate groups of spikes in our spectrum as they have different nuclear spins. Naturally, rubidium consists 72% of Rb-85 with a nuclear spin of $I = 5/2$ and 28% of Rb-87 with a nuclear spin of $I = 3/2$, a more detailed analysis of this transition can be seen in figures 1 and 2 below.

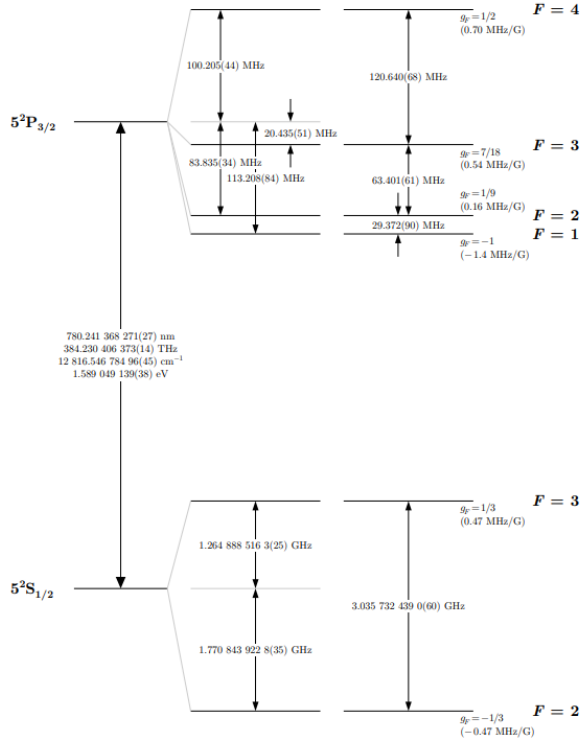


Fig. 1: This image shows the Rb-85 D2 transition hyperfine structure.

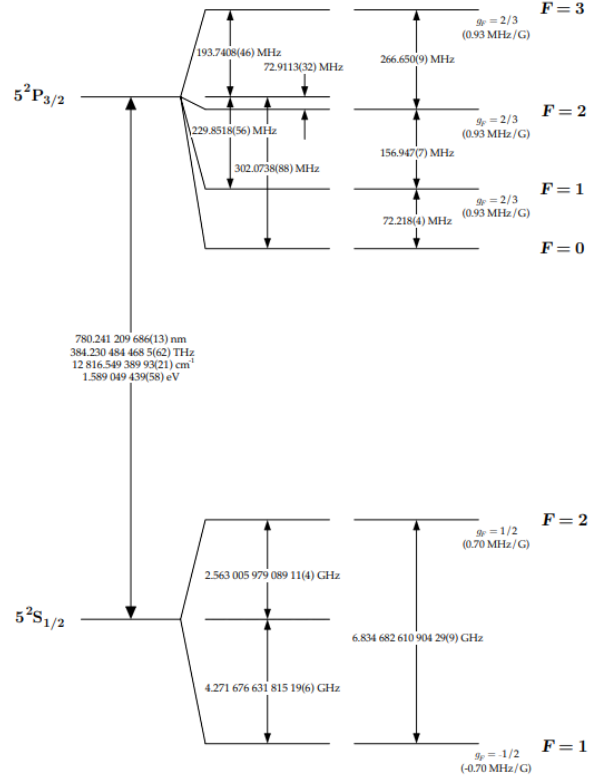


Fig. 2: This image shows the Rb-87 D2 transition hyperfine structure.

At room temperature, the Doppler width of an isolated transition in rubidium is around 500 MHz. In order to resolve these transitions, we will need to employ the technique of Saturated Absorption Spectroscopy.

II. LAYOUT AND EQUIPMENT

This experiment will use the ThorLabs TC200 temperature controller to gently heat the rubidium cell from room temperature. It will then be detected by the Fabry-Perot interferometer. We will also be using the ThorLabs TED200C temperature controller to change the temperature of the laser diode with our thermoelectric device, ThorLabs LDC-200C laser diode controller. The LDC-200C will be connected to the Siglent SDG 1032X function generator to sweep the laser frequency back and forth around a set value. The output from the function generator, along from

the Fabry-Perot interferometer and detectors M- and M+ will be displayed on an Oscilloscope for us to see throughout the procedure of our experiment.

The Fabry-Perot interferometer will serve as our frequency reference while the laser is in use. This instrument consists of two mirrors which reflect most of the light entering the interferometer unless the light matches a resonance of this condition:

$$m\lambda = 2l \quad (1)$$

Where l is the separation in mirrors, m in an integer, and λ is the wavelength of light. This results in the periodic transmission with peaks separated by $\Delta f = c/2l$, which coincides with $\Delta f = 1.5\text{GHz}$ for our interferometer.

The apparatus for our experiment is shown below:

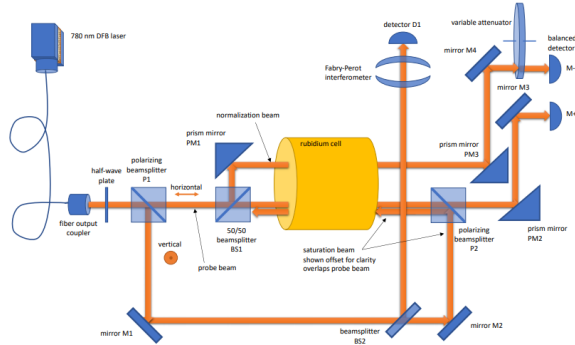


Fig. 3: Our Experimental Setup for this Lab.

When conducting the experiment, begin with a piece of paper set up before mirror M2. This is done to achieve the unsaturated absorption peaks of rubidium.

III. PROCEDURE

To begin the experiment, we must first turn on the Thor Labs TC200 temperature controller along with the Fabry-Perot interferometer and the detectors at the end of the laser beam paths (M- and M+).

Now, we must turn on the laser along with the TED-200C temperature controller. We must first check that our T_{act} is set at around 11 k Ω , this is for our thermistor that will measure the temperature in the laser. This thermistor measures temperature from a resistor whose resistance varies with heat in a known way, 11 k Ω is approximately room temperature.

We must also set T_{set} to 10.000 k Ω before changing the display back to T_{act} . We must then press the “TEC ON” button to see the thermistor value change to the set value of 10 k Ω . We are now finished with the TED-200C.

To continue, we must turn on the LDC-200C and adjust the current knob so that it is fully counter clockwise,

Now pressing after “Laser On” button, we should see approximately zero current. Adjust the knob until the display shows 70 mA.

Now, connect the LDC-200C to the 1032X function generator. Turning on the function generator, select “Waveforms” and then “Ramp”. Next, we want to set the frequency to 70 Hz and the amplitude to 500 mVpp, ensuring the offset is zero. After pressing the “Output” button on channel 1, connect a BNC cable to the first input on the oscilloscope. We are done with the function generator for now.

We must now adjust the time-base of the oscilloscope to 500 μs per division and then make small adjustments to the frequency of the function generator and the horizontal position on the scope so that we get one half period of the ramp shown on the scope. A successful example of this is shown below.

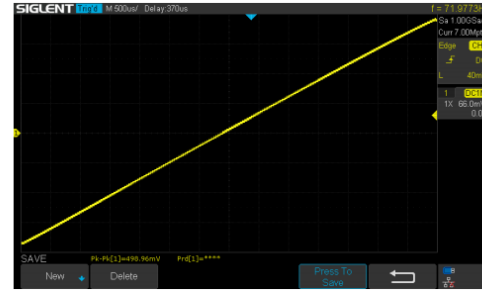


Fig. 4: One half period of the ramp shown over the oscilloscope.

Now, we must connect the output of the detector behind the Fabry-Perot interferometer to input 2 of the oscilloscope. We should begin to see transmission peaks as the laser sweeps through resonance with the Fabry-Perot. We must make sure to adjust the gain and vertical offset of this input so that the peaks can be seen clearly. A successful example of this is shown below.

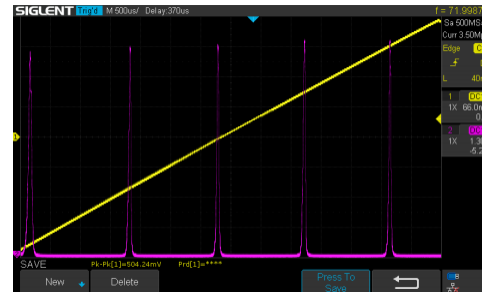


Fig. 5: Transmission peaks shown in the oscilloscope.

The peaks shown in Figure 5 are separated by 1.5 GHz. We can use this to measure details of our data later in the experiment.

Now we must connect the “M-” detector output to channel 3 of the scope. We should see a vertical gain of roughly 200mV/division. We also must adjust the vertical position of this input so that zero is at the very bottom. There should be a slight change in signal from left to right of the scope, this is the effect of the laser current causing the laser power to change somewhat as we scan. We can see this displayed in the example below.

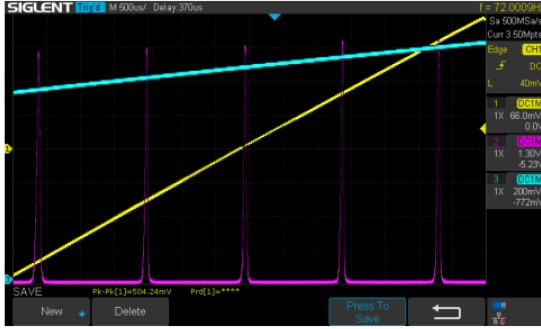


Fig. 6: A slight change in signal is shown by the blue line, this is our laser power.

Next, we must slowly adjust the T_{set} knob on the TED200C until the thermistor value is around 7.07 k Ω . We can observe the Fabry-Perot resonance shift rapidly as the center frequency of the laser changes. We may need to make slight adjustments, but we should observe all four Doppler-broadened absorption peaks of rubidium the D2 line on the oscilloscope as shown in the example below.

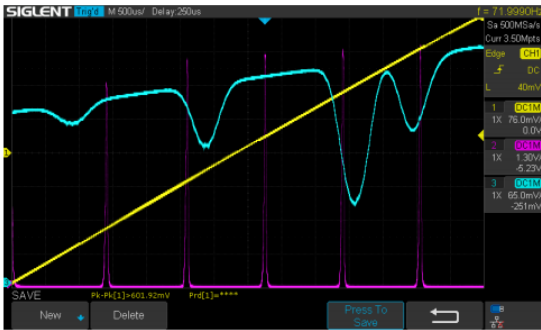


Fig. 7: The four Doppler-broadened absorption peaks of the rubidium D2 line shown in our oscilloscope.

Now, we can remove the card that is set up before the M2 mirror. We should begin to see saturation peaks in the absorption resonances that are much narrower than the Doppler width. We can see this shown clearly using the example in Figure 8.

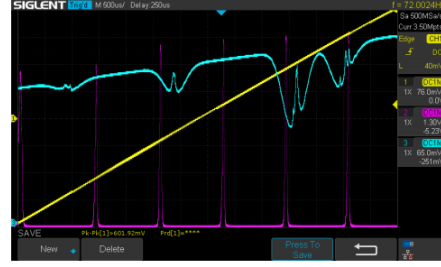


Fig. 8: The Saturated Absorption Spectra of our four Doppler-broadened peaks shown in our oscilloscope.

Continuing, we must connect the “RF output” from the “M+” detector to channel 4 of the oscilloscope. We can set the vertical gain to roughly 2 Volts per division and the vertical position near the top of the screen for best results. We can also adjust the attenuator wheel shown before the detector in Figure 1 so that the level is zero away from the resonances. After removing trace 3, we can clearly observe the results of this new input in the example below.

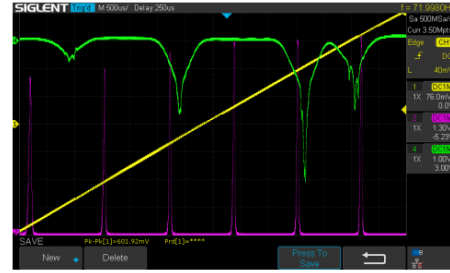


Fig. 9: Our pure Saturated Absorption spectrum shown in our oscilloscope.

We have just successfully subtracted the Doppler-broadened absorption peaks (Figure 7) with the Saturated Absorption spectrum (Figure 8) to get our pure saturated absorption spectrum. We can zoom in on the various hyper-fine components by making slight changes to the temperature and lowering the amplitude of the function generator. For example, we show below the excited state of 87Rb.

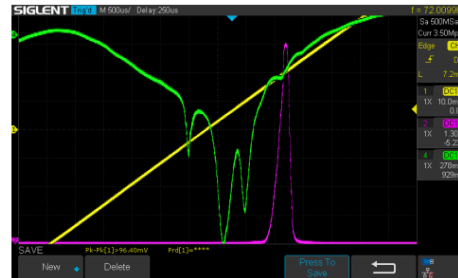


Fig. 10: Rubidium 87 F=2 peak example shown in our oscilloscope.

We can use these saturated absorption peaks to measure the hyper-fine splitting of RB-85 and RB-87, along with determining the transitions within the upper-level hyper-fine components.

IV. DATA/ANALYSIS

When conducting this experiment, we were able to determine the hyper-fine slipping of rubidium D2 by recording our data for the Doppler-broadened absorption peaks as seen through the example in Figure 5. Our data is shown below.

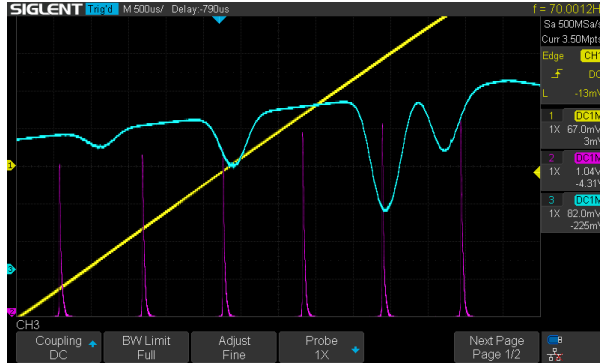


Fig. 11: Our measured absorption peaks of the rubidium D2 transition line.

We were able to successfully identify which peaks we were observing along with the distances between them by using the transmission peaks as a reference. Starting from the left in Figure 11, we have the ground state of Rb-87 (F=1) at the furthest left, then the ground state of Rb-85 (F=2) at the middle left. Next, we have the excited state of Rb-85 (F=3) at the middle right, followed by the excited state of Rb-87 (F=2) at the far right.

The ground state hyper-fine splitting of Rb-85 and Rb-87 are displayed in the table below.

Energy Level Transitions	Frequency splittings
RB-87 F=1 \rightarrow Rb-87 F=2	6.081 ± 0.5 GHz
RB-85 F=2 \rightarrow Rb-85 F=3	2.71622 ± 0.5 GHz

We were able to measure these values by printing out Figure 11 and measuring the distances between the transition peaks with a ruler. We then converted this measurement to frequency by using the given distance between the transmission peaks, as shown in Figure 3, to be 1.5 GHz as a standard unit to divide our measurements.

Furthermore, we also attempted to identify the transitions to the upper-level hyper-fine components of Rb-85 and Rb-87. Our raw data is shown in Figures 12 and 13.

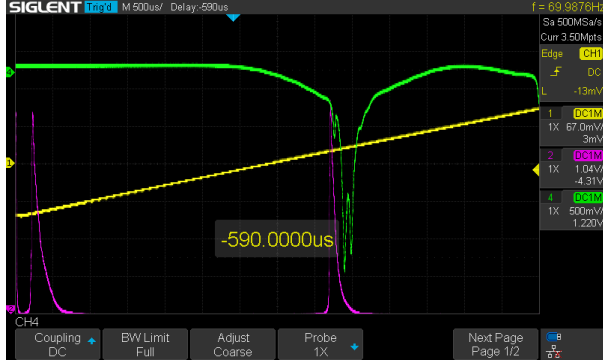


Fig. 12: The zoomed in excited state of Rb-85, F=3

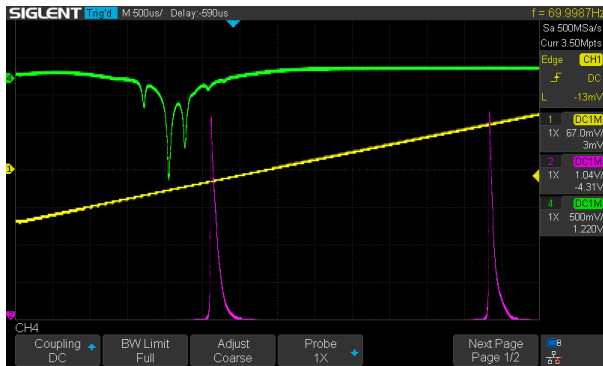


Fig. 13: The zoomed in excited state of Rb-87, F=2

V. CONCLUSION

This lab found us able to identify the four peaks in the absorption spectrum of Rubidium while also being able to measure the ground state hyper-fine splitting of Rb-85 and Rb-87. As we had to print out each of the images to measure the frequency splitting of Rb-85 and Rb-87, we encountered error in our ruler measurements that was equivalent to ± 0.5 GHz.