

# Diode Laser

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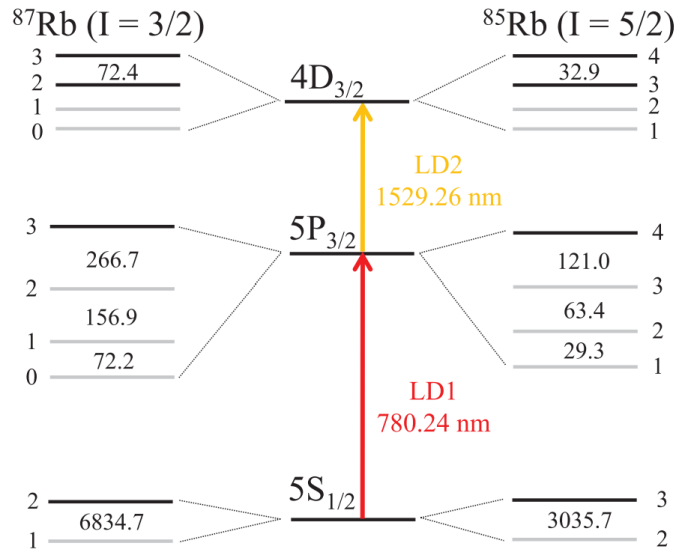
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## ABSTRACT

In this experiment, we use laser diode spectroscopy to excite two rubidium isotopes,  $^{85}\text{Rb}$  and  $^{87}\text{Rb}$ . These isotopes have hyperfine splitting of their energy levels due to the interactions of the magnetic dipoles in electrons with the magnetic nucleus. Because of this, there are two transitions from the ground state to the first excited state for each isotope, making the total number of peaks on the absorption curve four. Once this curve is obtained, the next step is to set up a Michelson Interferometer so that interference that results gives an optical frequency difference. This frequency difference, when paired with the peak-to-peak range of the absorption curve, gives the transitional frequency of the isotopes. We find this frequency to be 6.899 GHz, which is 0.94% from the expected value.

## 1 Introduction

Diode lasers produce tunable narrow-bandwidth radiation, making them useful for a variety of optical experiments. In this optical spectroscopy experiment, we measure the absorption spectrum of two rubidium isotopes:  $^{85}\text{Rb}$  and  $^{87}\text{Rb}$ . The rubidium isotopes each have a ground state,  $5S_{1/2}$ , and an excited state,  $5P_{3/2}$ . Each of these states has hyperfine splitting shown in Fig. 1. Hyperfine splitting is the splitting of degenerate energy levels due to interactions of the magnetic dipoles in electrons with the magnetic nucleus of the atom.



**Figure 1.** Hyperfine structure of the two rubidium isotopes,  $^{85}\text{Rb}$  and  $^{87}\text{Rb}$ . The ground state,  $5S_{1/2}$ , shows two states due to hyperfine splitting.<sup>1</sup> The peaks in the absorption curve correspond to a transition from this split ground state into the first excited state,  $5P_{3/2}$ . On the graphic, this corresponds to a transition from states 1 and 2 from  $5S_{1/2}$  into state 1 from  $5P_{3/2}$ . Each isotope undergoes both transitions, so the absorption curve has four peaks. (Note: the  $4D_{3/2}$  state in the graphic does not apply to our specific experiment.)

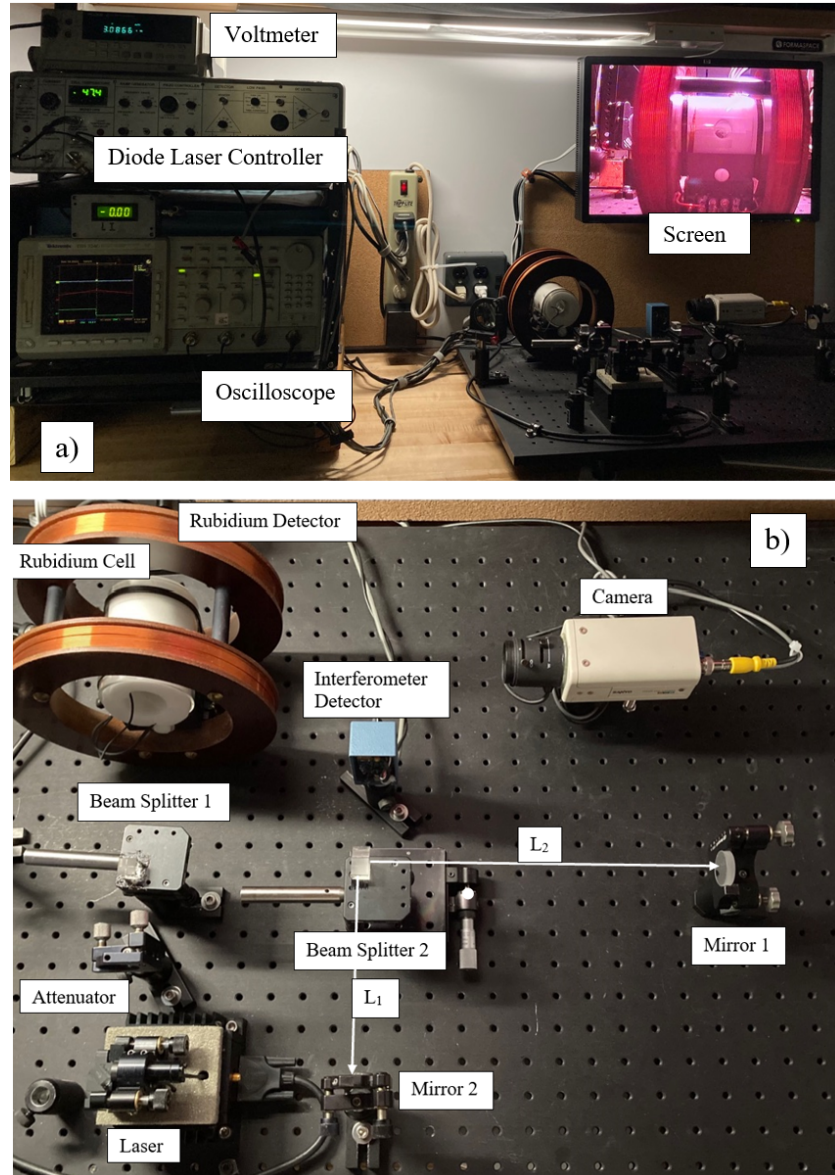
As photons from the laser enter the rubidium cell, the photons with energy equal to the excitation energy of electrons in rubidium get absorbed, resulting in a transition. When the laser exits the rubidium cell, only the photons that did not get absorbed are detected by the photodiode detector. This allows us to see what frequencies of photons are absorbed from the frequency sweep of the laser. The signal from the detector gives us the absorption spectrum of rubidium. Due to the hyperfine splitting mentioned above, each isotope has two peaks in the absorption curve, one from state 1 of  $5S_{1/2}$  into state 1 of  $5P_{3/2}$  and

17 another for state 2 of  $S_{1/2}$  into state 1 of  $P_{3/2}$ <sup>1</sup>.

18 Once we have an absorption curve, we determine the transition frequency by using a Michelson interferometer to calibrate  
19 the frequency variation of the laser. This allows us to quantify the energy separation of the peaks in the absorption spectrum. To  
20 do this, we must determine the optical frequency difference,  $df$ , by

$$df = \frac{c}{2D_L}, \quad (1)$$

21 where  $c$  is the speed of light and  $D_L$  is the difference in the interferometer arm lengths. Multiplying  $df$  by the number  
22 of periods of the interferometer waveform that fit between the peaks in the absorption spectrum yields the actual frequency  
23 separation of the energies.



**Figure 2.** a) Equipment to control the laser and measure the output from the detectors. The oscilloscope gives us the absorption curve and interferometer fringes. The screen is used to ensure the rubidium is being excited as it shows the infrared emissions. b) Setup of the laser, rubidium cell, and interferometer. The attenuator ensures that the oscilloscope does not receive too much signal from the laser. Beam splitter 1 allows the laser to enter into the rubidium cell and the interferometer. The interferometer is made up of beam splitter 2, both mirrors, and the detector. The camera is used to output a signal to the screen.

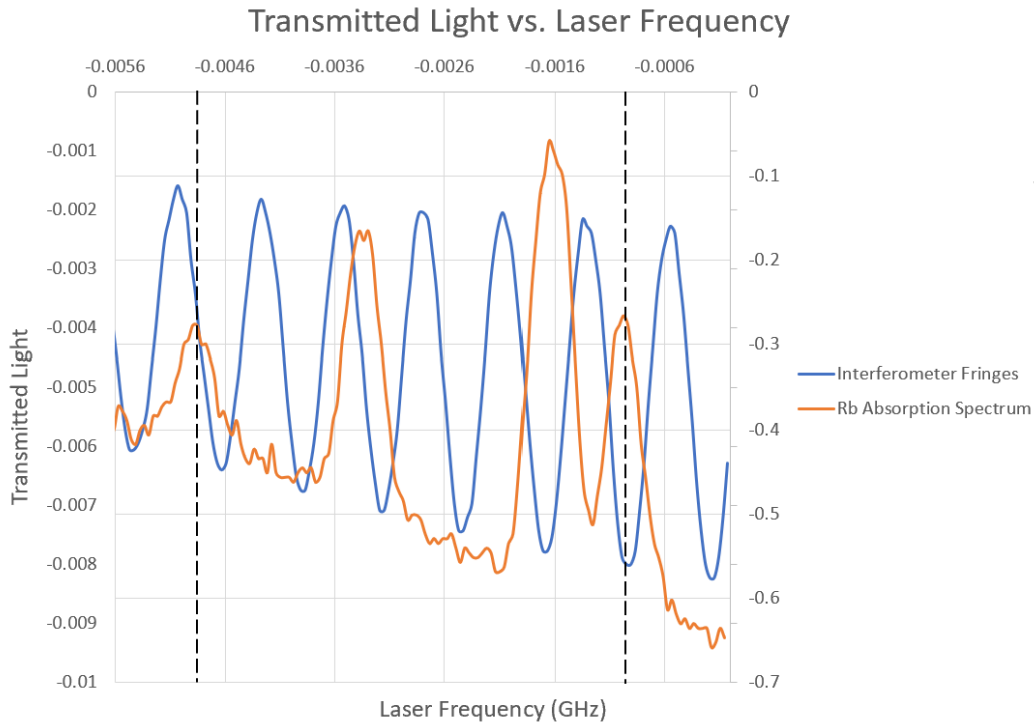
## 2 Experimental Setup

Our experimental setup consists of a system of mirrors, two light detectors, a container of Rubidium isotope vapor, a diode laser apparatus, an oscilloscope, and a voltmeter, as shown in Fig. 2. The mirror system includes a Michelson interferometer setup. At the beginning of the mirror system, a beam splitter creates a path to the Rubidium container and a path to the interferometer. We place light detectors behind the Rubidium container and at the end of the interferometer. We connect the light detectors to different channels on the oscilloscope. When we fire the laser through the mirror system, the oscilloscope simultaneously displays the signals from both detectors, which correspond to the absorption spectrum of the Rubidium isotopes and the frequency range of the interferometer fringes. We export the numerical data from the oscilloscope for further analysis.

The diode laser apparatus includes an internal ramp generator and a piezo stack. The ramp generator controls the current supplied to the laser. The stack allows us to change the grating angle of the blazed grating in the laser emitter, controlling the frequency sweep. The voltmeter reading corresponds to the temperature of the laser emitter; the voltage must be close to 3.086V for the laser to operate properly. The laser apparatus includes a thermometer for the temperature of the rubidium, which must be around  $50^{\circ}\text{C}^2$ .

## 3 Results

Our first experiment gave us the absorption curve depicted by the orange curve in Fig.3. Next, we used the interferometer setup shown in Fig. 2. In our experiment, we use  $L_1 = 0.148$  m and  $L_2 = 0.261$  m. So,  $D_L = 0.113$  m. Using this along with Eq.(1), we get that  $df = 1.3265$  GHz. To find the transitional frequency, we estimate the number of interferometer fringes within the domain of our absorption spectrum peaks (depicted by the black dashed lines in Fig.3) and multiply that number by  $df$ . The number of fringes in our domain of absorption spectrum has 5.2 interferometer fringes, which gives our transitional frequency as 6.899 GHz.



**Figure 3.** Graph of transmitted light vs. laser frequency with the interferometer setup. The vertical axis to the left of the graph shows the relative light intensity of the Rb absorption curve. The vertical axis to the right of the graph shows the relative light intensity of the interferometer fringes. The dashed lines show where the peak-to-peak range of the absorption curve coincides with the interference pattern from the interferometer. The number of interferometer fringes within this range is used to find the difference in frequency, which is found to be 6.90 GHz. This difference corresponds to the frequency gap between the ground states and the first excited states of the Rb ions.

## 4 Conclusions

The expected result of the transitional frequency for  $^{85}\text{Rb}$  and  $^{87}\text{Rb}$  is 6.835 GHz<sup>2</sup>. Our result is within 0.94% of the expected value, indicating that our result is conclusive. The goal of the experiment is accomplished since we found the transitional frequency and obtained an absorption curve that shows the two transitions for each rubidium isotope. Our experiment with diode laser spectroscopy can be used for gas diagnostics and air quality monitoring<sup>3</sup>. One can use the absorption spectra of certain atmospheres to find the chemical components and use that to determine any harmful components of the atmosphere.

## References

1. Lee, W.-K. & Moon, H. S. Measurement of absolute frequencies and hyperfine structure constants of  $4D_{5/2}$  and  $4D_{3/2}$  levels of  $^{87}\text{Rb}$  and  $^{85}\text{Rb}$  using an optical frequency comb. *Phys. Rev. A* **92**, 012501 (2015). URL <https://link.aps.org/doi/10.1103/PhysRevA.92.012501>. DOI 10.1103/PhysRevA.92.012501.
2. Abraham J. Olson, E. J. C. & Mayer, S. K. Two-photon spectroscopy of rubidium using a grating-feedback diode laser. *Am. J. Phys.* **74**, 218–223 (2006). URL <https://doi.org/10.1119/1.2173278>.
3. Martin, P. A. Near-infrared diode laser spectroscopy in chemical process and environmental air monitoring. *The Royal Soc. Chem.* **2002** **31**, 201–210 (2002). URL <https://doi.org/10.1039/B003936P>.