Diode Laser Spectroscopy

CHARACTERISTICS OF THE TUNABLE DIODE LASER

Students can begin these labs by studying the laser itself. Without the grating feedback, they can examine both the threshold current for lasing and the wavelength as a function of laser temperature. The wavelength can be measured with either a "homemade" spectrometer or any commercial spectrometer already on hand. Students can also observe mode hopping in the laser.

With the grating feedback in place, students can observe the laser's wavelength stability, the frequency sweep (using both grating angle and current modulation), and the sweep interruptions due to mode hopping. It is also possible to change the external cavity length and measure its effect.

The simplest form of optical spectroscopy, is shown below in Figure 1.

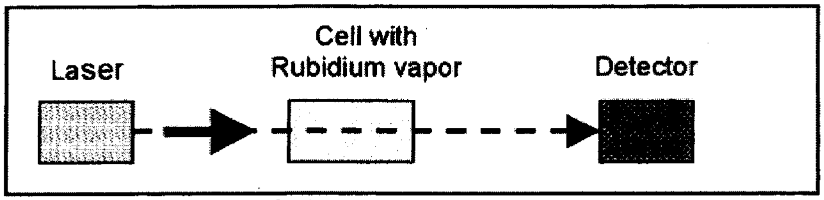

Figure 1: Block Diagram for Transmission Spectroscopy

The frequency swept laser light is passed through a cell containing rubidium vapor and the transmitted light is detected. Data for natural rubidium is shown in the oscilloscope capture below.

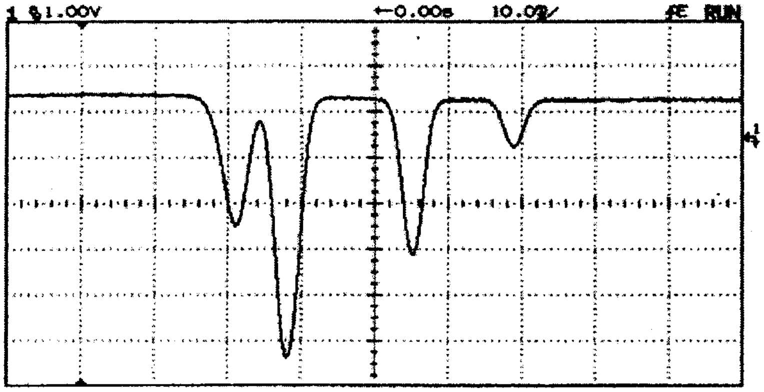

Figure 2: Transmitted Light vs. Laser Frequency

The broad absorption peaks observed by this method correspond to transitions between the ground $S_{1/2}$ and the exited $P_{3/2}$ states of both isotopes of rubidium.

These transitions are designated"a" and "b" on the energy level diagrams in Figure 3.

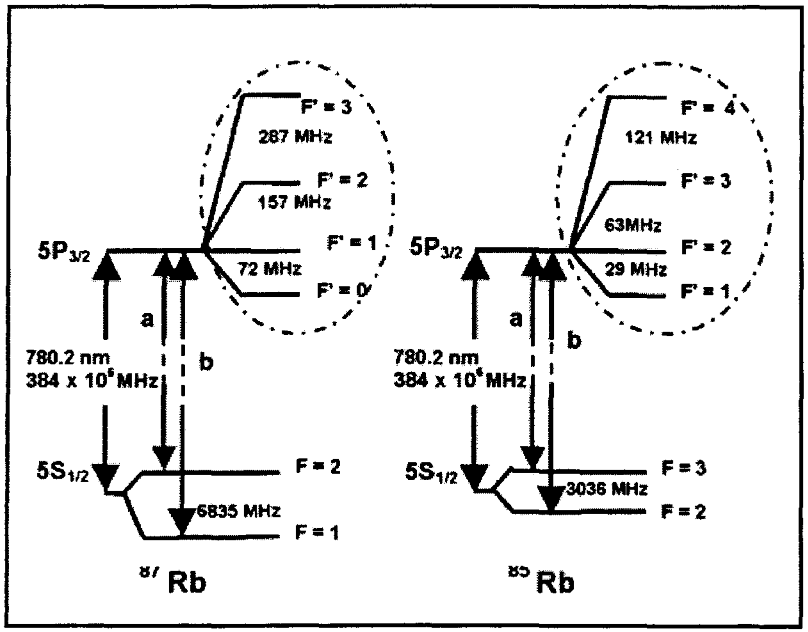

Figure 3: Rubidium Atomic Energy Level Diagrams

This "simple" laser technique easily resolves the ground-state hyperfine splitting of both isotopes but Doppler broadening obscures the far smaller hyperfine splitting of the exited state.

A CCD camera, connected to a TV monitor, is used to observe the infrared fluorescence which occurs when the laser is properly tuned to these hyperfine transitions. Note that the laser sweep is broad enough to cover both lines of both isotopes.

SATURATED ABSORPTION SPECTROSCOPY
Now the fun begins. The students rearrange the apparatus so that the single laser beam is split into two collinear beams, a probe (weak) and a pump (strong) which are sent through the rubidium cell in opposite directions. The block diagram in Figure 4, below, shows one possible experimental configuration.

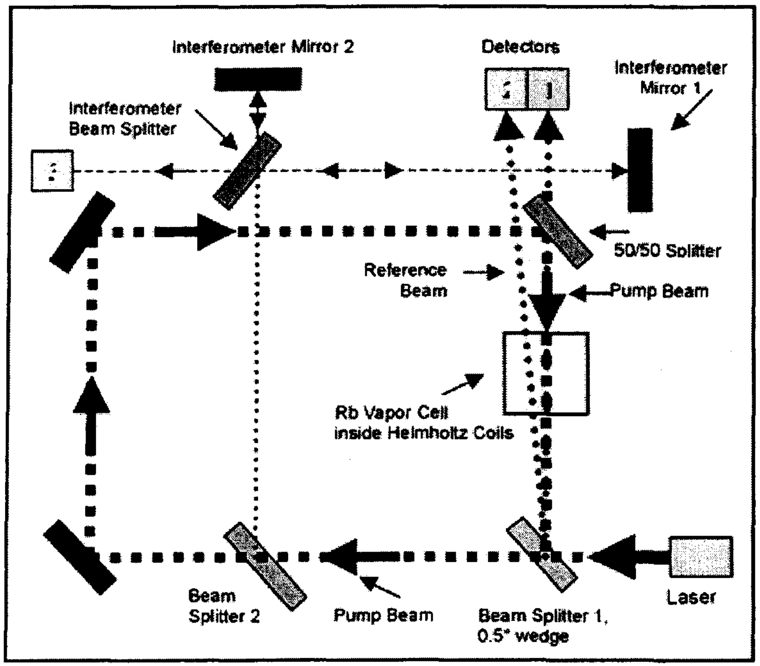

Figure 4: Block Diagram for Transmission Spectroscopy

As the laser sweeps through an actual transition frequency, however, both pump and probe beams interact with the atoms having zero longitudinal velocity. Because the much stronger pump beam "saturates" the transitions, the intensity of the probe beam light reaching Detector 1 increases, producing the narrow features shown in Figure 5.

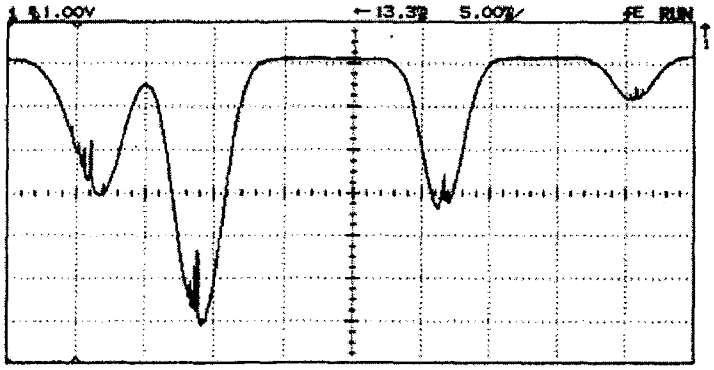

Figure 5: Transmitted Light vs. Laser Frequency: (Narrow Features Indicate $5P_{3/2}$ Hyperfine Structure)

Reflection at the second interface of the initial beam splitter produces the *reference beam* which does not overlap the pump beam as it passes through the rubidium vapor on its way to Detector 2. The electronics of the controller allow us to subtract this reference beam from the probe beam, removing the doppler background and leaving only the narrow features. Figure 6 shows this result dramatically for the ground state F=2 transition (transition "a") of ^{85} Rb. With line widths of about 10 MHz, these features represent a resolution (Δf/f) of about one part in forty million!

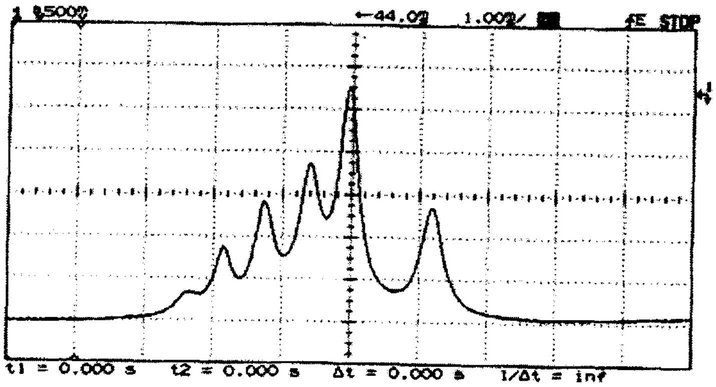

Figure 6: Features with Doppler Backgroud Removed (Please forgive the tilt!)

Given the ΔF = 0, ±1 selection rules, the energy level diagram of ^{85}Rb in Figure 3 suggests that there should be on *three*, not six, transitions from F = 2. The *six* peaks seen in Figure 6 include an additional three *crossover transition* peaks. These additional peaks, at frequencies exactly halfway between pairs of "actual" transition frequencies, arise from atoms moving at non-zero velocities such that the pump is in resonance with one transition and the probe is in resonance with the other transition.

USING THE INTERFEROMETER TO CALIBRATE THE SWEEP

In order to make quantitative measurements of the hyperfine splittings and compare these measurements to the handbook date, it is essential to calibrate the frequency sweep of the laser. This is accomplished with an unequal-arm interferometer shown the the upper section of the block diagram of Figure 4.

Beam splitter 2 diverts a small portion of the laser light into the interferometer assembly. The interferometer beam splitter divides the light, sending it to mirrors 1 and 2 along the long and short arms of the Michelson interferometer. Returning beams recombine and interfere at the beam splitter. Because of the unequal arm lengths, the frequency sweep of the laser generates a series of fringes in time, due to alternate constructive and destructive interference. Figure 7 shows a typical interference signal seen by Detector 3 along with the Doppler broadened transmission data.

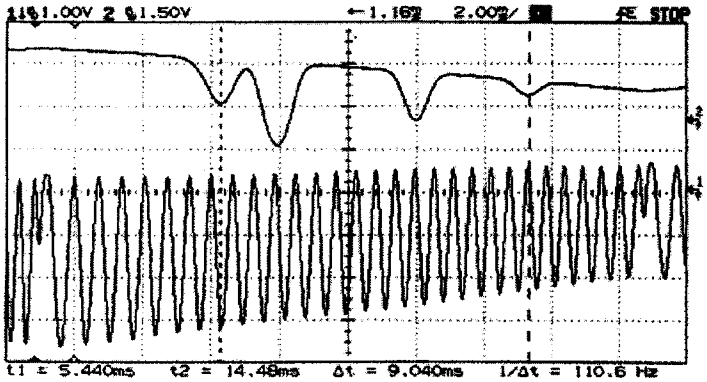

Figure 7: Transmission Data with Interferometer Fringes

Straight forward measurement of path lengths from the splitter to the mirrors can be used to calibrate the frequency sweep in Hz/fringe.

If $\Delta L = L_1 - L_2$ is the is the difference between the one-way lengths of the two arms, then the optical frequency difference, δf, between two successive maxima at the interferometer can be calculated as: $\delta f = c/2\,\Delta L$.

For our optical arrangement, with a path length difference of 0.35 meters, the sweep calibration is 0.429 GHz/fringe. This gives a 6.65 GHz frequency difference between the cursor marked features of Figure 7. The accepted value, shown on the energy diagram in Figure 3, is 6.835 Hz.

But this is by no means the end of the story. This unit can measure Zeeman splittings of the excited states, Faraday rotation in rubidium vapor, and the refractive index of rubidium as well as the Clausius-Claperyon relationship in rubidium.