

UNIVERSITY HONORS PROGRAM

SENIOR PROJECT - APPROVAL

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PROJECT TITLE: Resonance Ionization and Saturated Absorption
Spectroscopy of Cesium.

I have reviewed this completed senior honors thesis with this student and certify that it is a project commensurate with honors level undergraduate research in this field.

Signed: James E. Parks, Faculty Mentor

Date: 5/7/02

Comments (Optional):

Stephen did nice work on this project!

Resonance Ionization and Saturated Absorption Spectroscopy of Cesium

Stephen Wilson
Advisor: Dr. James Parks

Within this experiment the saturated absorption spectrum of cesium was explored and steps were taken towards the study of the resonance ionization spectrum. The $6S_{1/2}$ to $6P_{3/2}$ transition for $F=3$ and 4 was analyzed with the saturated absorption setup and compared to previous measurements. Following that, the resonance ionization spectrum was to be analyzed; however this phase was not completed due to unforeseen experimental complications.

Introduction

The use of saturated absorption spectroscopy allows the resolution of the hyperfine splitting structure within the energy levels of an atom. Specific energy transitions can thus be explored in the absence of the Doppler broadened absorption spectra, and the specific transitions within cesium were explored through this technique. An external cavity grating feedback laser diode system was used to excite the various energy level transitions in the experiment, and piezo-electronic tuning was utilized to continuously tune the wavelength of the laser between transitions. Two separate detection methods were employed in the saturated absorption portion of the experiment; one using a single photodetector and another using a quadrant detector. The resonance ionization spectrum of cesium was to be explored through the use of the two photon excitation process. The first excitation from $6S_{1/2}$ to $6P_{3/2}$ would be induced by the laser diode (~ 852 nm) system, while the second transition towards the ionization potential

would be excited by an argon ion laser system (~ 488 nm). This second transition must be induced before the initial excitation, induced by the 852 nm photon, has had time to relax to its ground state. Delays in procuring an effective gas cell for measuring the RIS spectrum and the argon ion laser's unforeseen breakdown have unfortunately hindered this portion of the experiment.

Absorption Mechanics and Theory

Within the basic concept of absorption, an incoming photon at a particular frequency has the capability to induce a resonance and excite a target atom. However, these resonances only exist for certain characteristic frequencies for each atom and depend on the specific energy transition that is being traversed. After absorbing the photon, the excited atom spontaneously reemits a photon of the same frequency in a random direction and then relaxes back into its original lower state. These specific resonances, however, are blurred within an absorption spectrum due to an effect called Doppler Broadening. At a given frequency off resonance, atoms moving with sufficient velocities see a Doppler shifted photon whose shifted frequency can excite the atom and broaden the natural line width of the resonance. For example, if the frequency of an incoming photon is tuned below the desired resonant frequency, an atom moving towards the photon sees a blue shift in the frequency of the photon. Thus for an atom moving with the appropriate velocity towards the photon, absorption and excitation of the atom will occur. This same principle applies for atoms moving away from the incoming photon when the frequency is tuned above the resonant frequency (red-shifted).

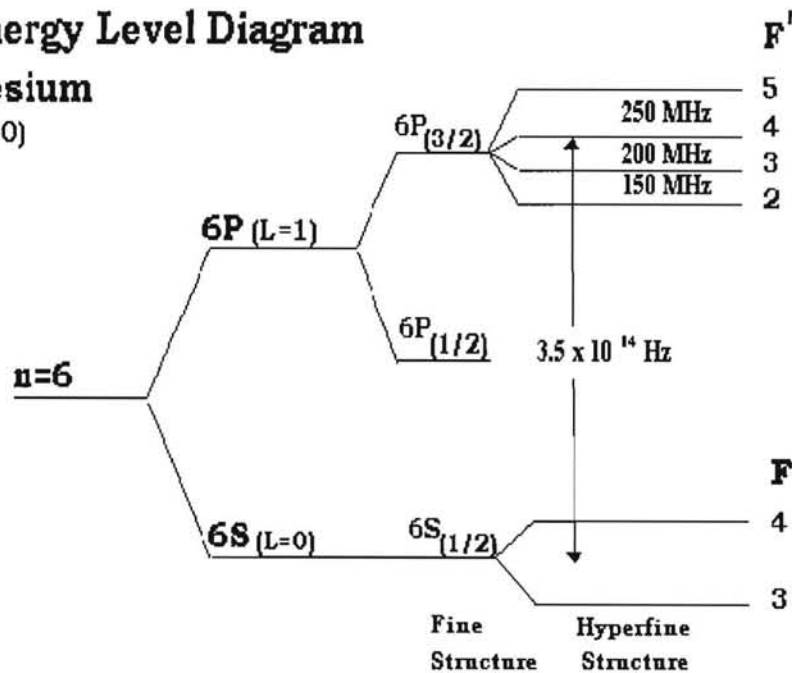
This absorption peak broadening phenomena can be overcome through the use of a counter propagating, saturating strong beam. When this second beam is added within the experimental setup, the Doppler free spectra appears and the hyperfine peaks within the energy levels can be resolved. This Doppler free spectrum arises from the combined interactions of the weak and strong beams with different populations of atoms. Specifically, when the frequency is tuned above resonance, the strong beam interacts with atoms moving away from it (red shifted downward) while the weak beam does the same. However, since the beams are counterpropagating, the two beams interact with atoms moving in different directions. This same concept applies when the frequency is tuned below the resonance; hence the two beams interact with two different populations of atoms. However, when the beam is tuned to resonance, both beams interact and try to excite the stationary atoms. If the intensity of the strong beam reaches the saturation intensity ($I_s = (\pi * h * \omega * \Gamma) / (\lambda^3)$ where Γ is the cross section) then the weak beam interacts with a depleted number of atoms in the lower state. The strong beam then effectively saturates and depletes the lower state leaving $\frac{1}{4}$ of the atoms in the upper state and $\frac{3}{4}$ in the lower state, and an analysis of the weak beam's absorption spectra reveals absorption peaks as the laser tunes across the hyperfine resonances. There are fewer atoms to absorb the weak beam photons and hence peaks emerge within its absorption spectra. Using this technique, the absorption spectra without the counter propagating strong beam can be subtracted from the spectra taken with the strong beam to further improve the resolution of the Doppler free spectra.

The energy level transitions explored in the experiment appear as follows:

Energy Level Diagram

Cesium

($B=0$)



The various splittings in the energy level diagram originate from the electron-spin orbital interaction and the nuclear spin orbit interaction. Fine structure splitting occurs from the accounting of electron spin (S) in the total angular momentum (J) where $J = L + S$.

The resulting possible values for J range in integer steps from $|J-S|$ to $|J+S|$, producing the splitting. Further splitting occurs when the nuclear spin (I) is taken into account. The values for F (where $F = I + J$) range from $|F-I|$ to $|F+I|$ in integer steps, and thus account for the hyperfine spectrum seen in the energy level diagrams. The possible transitions explored are governed by the selection rules and the energies of the incoming photon. Specifically transitions starting from the $6S_{1/2}$ $F = 3$ and 4 levels to the $6P_{3/2}$ hyperfine levels were analyzed in this experiment.

When one transition is excited and another photon excites the atom further before it can relax back to its lower level, the phenomenon of multiphoton excitation occurs. Through this process, the atom can be excited to various levels, and if enough energy is absorbed through the impinging photons, the atom can be ionized. Within this experiment, the cesium atom could be ionized through the two transitions from the $6S_{1/2}$

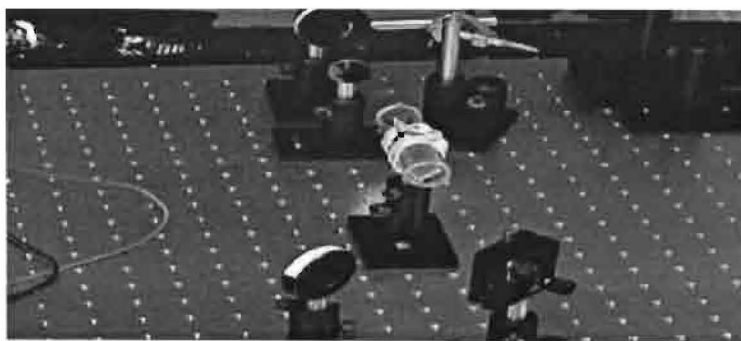
level to the $6P_{3/2}$ level and then by a 488 nm photon with enough energy to reach the ionization potential. Measuring the ionization current produced in the gas cell from this two-photon excitation allows for the exploration of the energy level structure of cesium via resonance ionization spectroscopy.

Experimental Procedure

Initially the saturated absorption portion of the experiment was setup. A commercial external cavity grating feedback laser system was setup to run at approximately 852 nm. The laser used a Littman-Metcalf setup for its grating feedback mechanism where the first order spot refracted off the grating was reflected off a mirror and then fed back off the grating and into the diode. The diode within the setup was anti-reflection coated to allow for continuous tuning across a broad range of wavelengths. This tuning was achieved through coarse adjustment of the mirror angle and then fine tuned adjustment of piezoelectric stacks behind the cavity mirror. The output light was attenuated with a neutral density filter (3.2% T) and reflected through a cesium vapor cell onto a photodetector. A CCD camera was used to monitor the output of the laser and the reemission from the cell when the cesium vapor was excited. Also a faraday isolator was placed at the laser output to avoid any feedback into the laser, which initially proved capable of creating false absorption peaks. The output of this system was then tuned to the 852 nm $6S_{1/2}$ to $6P_{3/2}$ transition. When the frequency was correct, absorption could be detected through the photon absorption and reemission in all directions along the path length of the laser through the cesium cell. Once the frequency had been coarsely tuned to near resonance, the piezoelectric tuning was used to sweep continuously across the

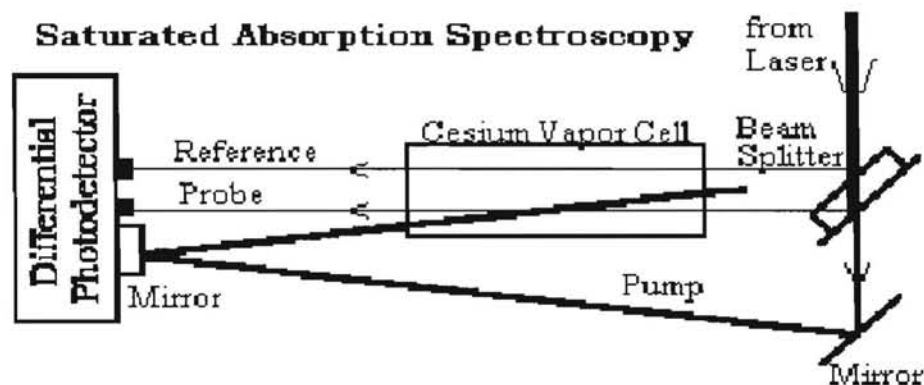
absorption spectrum. This was achieved through applying a sawtooth waveform of amplitude .5 Volts into the piezocontrol input. Full scale range of the piezoelectric sweep could be reached by applying a voltage of plus or minus 7 Volts since there was an internal amplification of a factor of 10 inside the control unit.

The first method of obtaining the Doppler free spectra was performed using the setup described with the addition of a mirror below the target photodetector. The neutral density filter was angled such that the 97% reflected portion of the impinging laser beam was reflected onto the mirror below the photodetector and then reflected back through the cesium cell. As it passed through the cesium cell, this strong beam was angled so that it maximally overlapped the weak beam it was counter propagating along. This allowed for the Doppler free spectra to be analyzed through the photodetector's observation of the weak beam. The frequency of the laser was oscillated along the absorption spectrum through piezoelectric tuning, and the resulting voltages from the photodetector were recorded. One run was taken with strong beam blocked and another with the strong beam counter propagating along the weak beam. The data from these two runs was then subtracted to reveal a well-defined hyperfine spectrum.



Setup for single photodetector saturated absorption spectrum

Another method involving only one data run was used to obtain the saturated absorption spectrum. This involved replacing the single photodetector with a quadrant detector, whose upper and lower quadrants were wired together. Within the electronics powering the quadrant detector, the upper and lower halves of the detector are subtracted from one another. To take advantage of this, a thin plate of glass was angled in the beam path after the neutral density filter, and the two parallel weak reflections from the surfaces of the glass were sent through the cesium cell. The separation between these two weak beams was adjusted such that one weak beam fell on the upper half of the quadrant detector and the other on the lower half. Then as before, the strong beam transmitted through the glass was reflected off of the mirror below the detector and reflected counter propagating along the path of the lower weak beam. This method allows for a single run acquisition of the hyperfine spectrum, and also avoids any laser drift occurring between runs in the two run method.

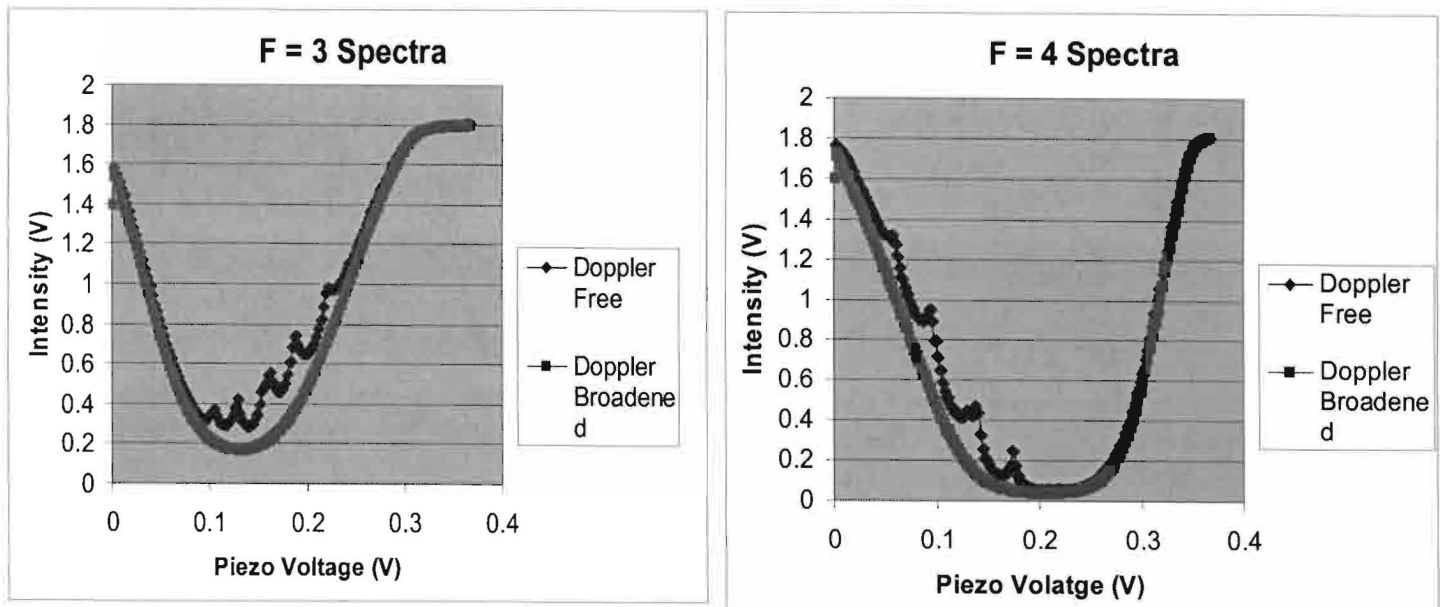


The next phase of the experiment involved implementing apparatus to acquire the resonance ionization spectrum of cesium. A new cell was constructed with two wires fed

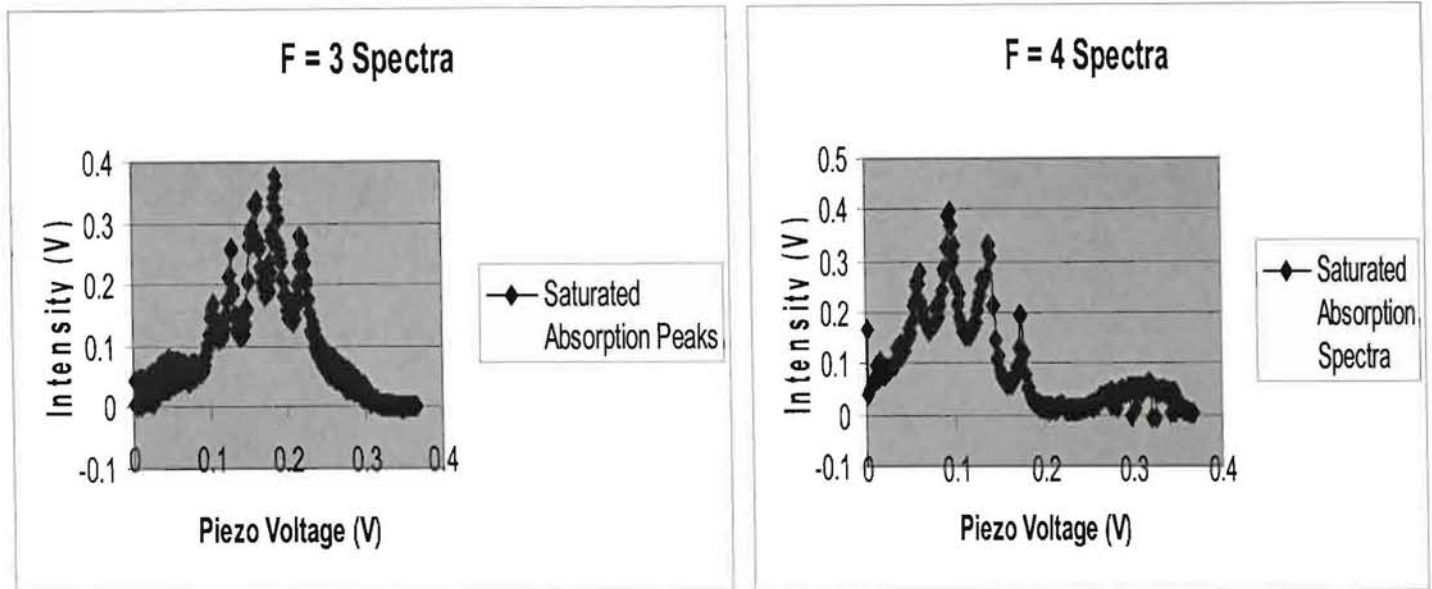
through on opposite sides of the cell and bent to run parallel to one another through the middle of the cell. The attenuator and glass plate were removed, and the output beam of the laser diode system was expanded to approximately 1 cm^2 in diameter. An argon laser system was then setup, and the beam directed to overlap the beam from the diode laser system. In order to measure the resulting current, a battery box with approximately 37 Volts was connected across the leads of the glass cell. The output from the box was then fed to a Pico ammeter, which would monitor the ionization current. Due to background current generated by room light exciting electrons within the tube, the entire experiment was walled in and covered. During this phase of the experiment, however, the argon ion laser ceased to function and is currently under repairs. Hence this portion of the experiment rests under temporary hold, but data has been collected and analyzed for the saturated absorption portion.

Saturated Absorption Results

The two run method with a single photodetector yielded the expected hyperfine structure. Although the second run of data had to be shifted slightly to account for laser drift between runs, the resolution of this approach proved to be high.



The hyperfine peaks are clearly visible and become further enhanced when the two spectra are subtracted.

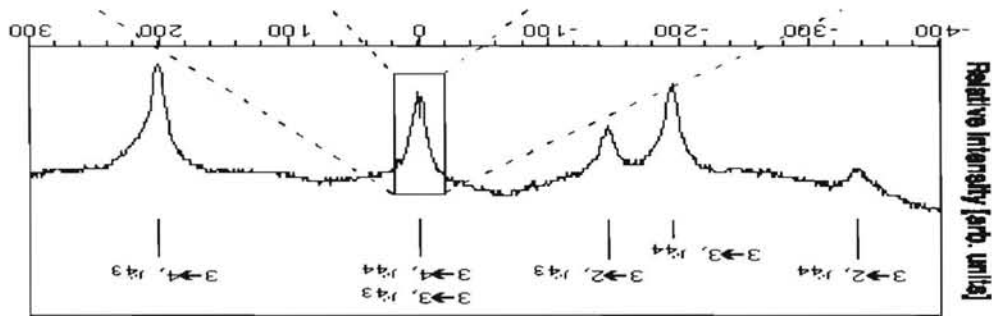


The existence of extra peaks between the expected hyperfine transition peaks of $F' = 2, 3, 4, 5$ are credited to a phenomenon called “cross-over” peaks. These peaks are caused by a further depletion of the atoms interacting with the weak beam when the laser is tuned exactly half way between hyperfine transitions. When the weak beam is tuned above resonance, the counter propagating strong beam depletes atoms, which would normally be induced to resonance by a red shifted photon from the weak beam. This strong beam instead induces a separate resonance with a blue shifted photon, and thus effectively depletes the population of atoms seen by the weak beam. Hence between every pair of real peaks, a cross-over peak emerges.

The second method of collecting the Doppler free spectrum was through the quadrant detector. The data for the $F = 3$ spectra looks as follows:



There exists an unexplained dip in the baseline of the spectrum, which is most likely is due to detector misalignment or reflected background at the absorption minimum. The full spectrum of hyperfine peaks and cross-over peaks remain visible despite this baseline curvature. A reference picture taken from another study of cesium's saturated absorption spectrum reveals consistent data.



Taken from: *Cesium Saturation Spectroscopy Revisited: How to Reverse Peaks and Observe Narrow Resonances* by Schmidt, Knaak, Wynands, and Meschede

This spectrum produced by a group investigating narrow resonances in the cesium spectrum confirms the hyperfine resolution seen within this experiment's data.

Future Analysis

The next step within the experiment is to accomplish the original goal of exploring the RIS spectrum of cesium with 852 nm and 488 nm transitions. Once the laser is functional again, the beams can be overlapped and the resulting current monitored. Another aspect of the experiment to be revisited in the future is the unresolved dip in the Doppler free spectrum produced by the quadrant detector. The active area of the quadrant detector can be better shielded from unwanted light sources during the data taking process, and the detector's electronics can be revisited.