Saturated Absorption Spectroscopy of Rb atoms and attempt to observe Single Ion fluorescence using trapped Ca^+ ions in a linear Paul Trap.

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Abstract

Two different works have been described in this report. The first work aimed to observe the Doppler-broadening free F=2 to F' transition in ^{85}Rb at different optical powers of the pump and probe beams using both counter-propagating as well as Co-propagating pump and probe beams, separately in two different experimental setups. The method of using copropagating pump and probe beams enables elimination of cross-over resonances. The second work aimed to observe single ion fluorescence in trapped Ca^+ ions in a linear Paul Trap.

Part 1: Saturated Absorption Spectroscopy

Introduction

In this work the Doppler-broadening free spectrum of ^{85}Rb F=2 to F' transition was obtained by two different experimental techniques. In one of the experiments the standard technique of using counter-propagating strong pump beam and weak probe beam was employed to get rid of the Doppler broadening. Since the beams are oppositely directed only those atoms which have a zero velocity component in the direction of beam propagation can be in resonance with both the beams simultaneously. Since the same group of atom(zero velocity group) interacts with both the pump and the probe beam, the strong pump beam saturates the transition and this is manifested as a dip in the absorption profile of the probe beam. If Doppler broadened profile of the probe beam in the absence of the pump beam is subtracted from the profile in the presence of the pump beam, the Doppler free dips are left over. But this technique has a drawback in the sense that for multilevel atoms with several closely spaced energy levels within the Doppler broadened profile, some extra resonances, called cross-over resonances come into the picture. During scanning, when the laser frequency is exactly in between two transitions, the pump beam excites one of the transitions of a particular velocity group of atoms while the probe beam excites another transition of the same group, leading to reduction in absorption of the probe beam. This results in appearance of additional dips in the absorption profile of the probe beam. The technique of using copropagating pump and probe beam overcomes this problem and this method has been employed in the second experiment. The pump laser is locked to one of the peaks of ^{85}Rb F=2 to F'=3 transition and its absorption is being monitored. The probe laser is being scanned around this transition frequency. Since the pump beam is locked to a particular transition it is interacting only with the zero velocity group atoms and has no Doppler broadening in its profile. Now as the probe laser is being scanned it comes into resonance with the transitions of the zero velocity group atoms and this results in a dip in the absorption profile of the pump beam. The advantage of the second technique over the other is two fold. First the crossover resonances are eliminated. Second the spectrum is obtained against a flat Doppler free background.

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Experimental Procedure

Grating stabilized 780nm diode lasers were used for both the works. In the first method a beam from a single diode laser was split into two using a PBS and one of the beams were made to counter-propagate with the other one inside the Rb cell using mirrors and another PBS. A 500Hz mechanical chopper was used for chopping the pump beam. The signal from the photodiode was given to a SRS830 DSP Lock-in Amplifier which separated out the time varying portion of the signal, that is just the dips from the Doppler broadened background. The laser was scanned very slowly at 0.2Hz and long integration time (300ms) was used, so that background Doppler profile gets cancelled out as noise. The powers were varied using a PBS and a half wave-plate. The following pump and probe powers were used:

	Probe Power (μW)	**Pump Power** (μW)
A1a	4.4	18.9
b	4.4	22.1
c	4.4	28.5
d	4.4	42.1
A2a	4.9	14.9
b	4.9	19.1

**All powers have been measured just before the beam enters the Rubidium Cell using a Thorlabs Optical power meter.*

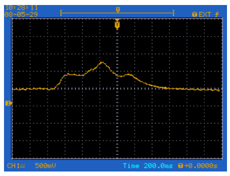
For the second experiment two grating stabilized 780nm diode lasers were used. One of the lasers was locked to the F=2 to $F^{'}$=3 transition of ^{85}Rb using a conventional saturated absorption setup with counter-propagating pump and probe beam. The other laser was being scanned over a frequency range of about 150MHz by changing the grating angle. Another saturated absorption setup was used to ensure that the laser was being scanned around the correct frequency range. Both the beams were made to copropagate through a third Rb vapor cell and the absorption profile of the locked pump laser was observed. As before the powers were varied using a PBS and a half wave-plate. Observations were made at the following different pump and probe beam powers.

	Pump Power (mW)	**Probe Power** (mW)
B1a	0.29	0.13
b	0.29	0.30
c	0.29	0.45
d	0.29	0.60
e	0.29	0.74
f	0.29	0.88
B2a	0.38	0.38
b	0.38	0.76
c	0.38	1.14
d	0.38	1.52
e	0.38	1.92
f	0.38	2.11
g	0.38	2.28
h	0.38	2.66
B3a	0.45	0.45
b	0.45	0.90
c	0.45	1.35
d	0.45	1.80
e	0.45	2.25
f	0.45	2.70

**All powers have been measured just before the beam enters the Rubidium Cell using a Thorlabs Optical power meter.*

Results

The spectra obtained at different combinations of pump and probe beam powers have been depicted below. The figure numbers corresponds to the table above.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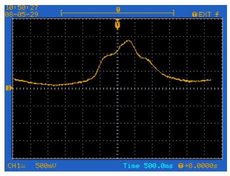
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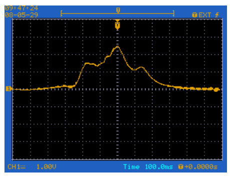
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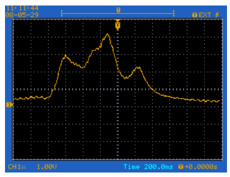
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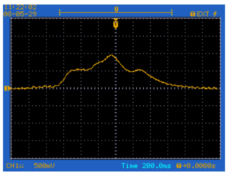
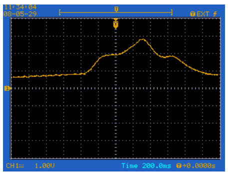
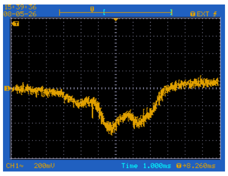
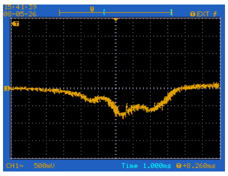
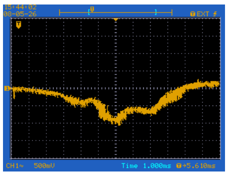
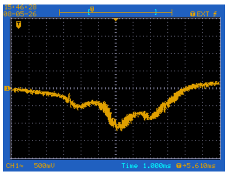
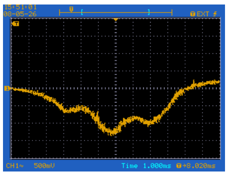
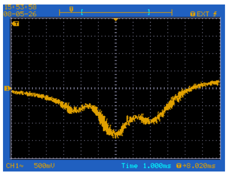
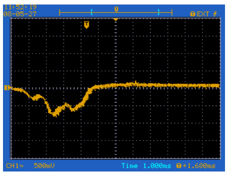
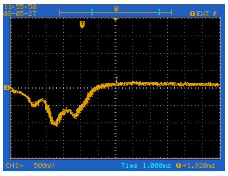
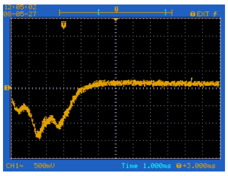
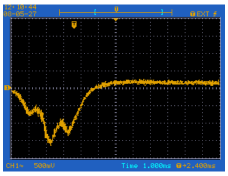
A2a.  A2b. 

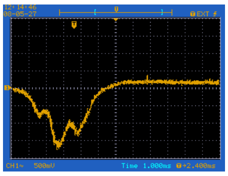
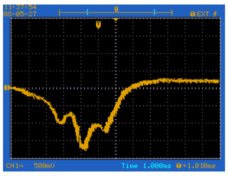
B1a.  B1b. 

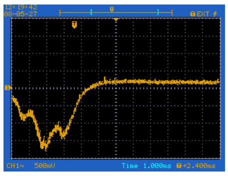
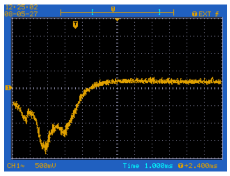
B1c.  B1d. 

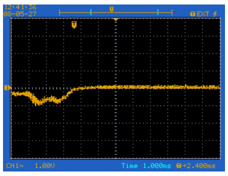
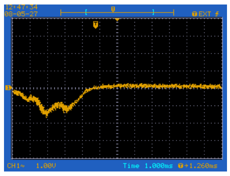
B1e.  B1f. 

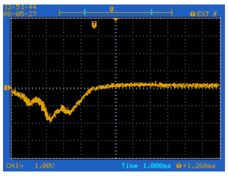
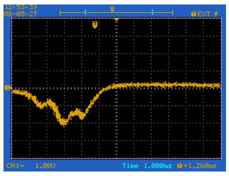
B2a.  B2b. 

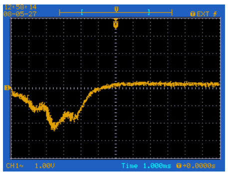
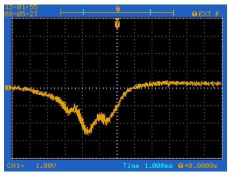
B2c.  B2d. 

B2e.  B2f. 

B2h.  B2g. 

B3a.  B3b. 

B3c.  B3d. 

B3e.  B3f. 

Part2: Single Ion Fluorescence

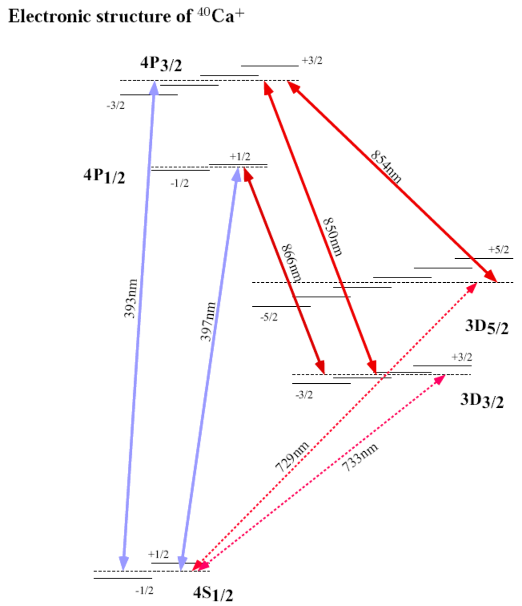
Introduction

In the second part of this work an attempt was made to observe single ion fluorescence of Ca^+ ions trapped in a linear Paul Trap. The aim was to trap a string of Ca^+ ions in the axis of a linear quadrapole ion trap and observe the fluorescence after excitation of the $^2S_{\frac{1}{2}}$ to $^2P_{\frac{1}{2}}$ level. The laser at 396.959nm was supposed to do both excitation of this transition as well as cooling of the ions. However optical repumping at 866.452nm is necessary to depopulate the meta-stable $^2D_{\frac{3}{2}}$ state into which the $^2P_{\frac{1}{2}}$ state decays.

Experimental Procedure

Trap Design

For our experiment we have used the same trap design as that used by Prof. Günter Werth′s group in the University of Mainz, Germany. The trap consisted



of three sets of four electrodes made of hollow stainless steel tubes with outer diameter of 6mm. The set of central electrodes were 15mm in length each, where as the electrodes in the two outer sets were 13mm in length each. Center to center distance between the electrodes was 8mm, both horizontally as well as vertically. Macor spacers were inserted in between the electrodes to separate them from one another. The electrodes were attached to two end plates which are in turn attached at their lower ends to a 74x30x3 mm base plate. The base plate was mounted on four adjustable stainless steel rods fixed to a CF100 Con-Flat flange. A convex lens with 25mm focal length is mounted over the trap for imaging fluorescence from the trapped ions with a camera. The entire assembly is put inside a vacuum chamber with quartz view-ports. The trap axis was aligned with the center of the two quartz view-ports at the side of the trap. A high frequency RF voltage was applied to the diagonally opposite electrodes in all the three sections and a positive DC potential was applied to the end electrodes only for axial confinement. The RF at 1.926MHz was generated using a Telulex Signal Generator, the particular frequency corresponded to the resonance peak of the ferrite core transformer used as a voltage amplifier for stepping up 9.5V_{p-p} to 180V_{p-p}. The Telulex signal generator allowed continuous stepping up of its output from 0V_{p-p} to 10V_{p-p} unlike the SRS DS345 being used previously. The system was maintained at 2E-7 torr by a Pfeiffer-Vacuum 60L/s turbomolecular drag pump backed by a Varian Rotary pump. While performing the experiment the chamber was filled with He buffer gas at 3E-6 torr. The purpose of using the buffer gas was to slow down the ions by collision with the buffer gas molecules.

Ion Source

For Ca atom generation we used a 2mm diameter and 3cm long glass ampoule filled with metallic calcium granules as our source. It was heated by passing 8A current through a tungsten filament coiled around it. A thoriated tungsten filament heated by passing 3A and maintained at -100V_{dc} with respect to a slit kept in front of it acted as an electron beam source for impact ionization of the Ca atoms.

Imaging System

The imaging system comprised of a programmable ANDOR Intensified-CCD camera with 10 stage intensifier gain, connected to a desktop computer having an ANDOR CC-010 PCI acquisition card. A telephoto lens attached to the camera ensured that the trap center was in focus. A 397±1 nm interference filter was attached in front of the lens. For image acquisition, ANDOR MCD software as well as a program written in ANDOR Basic was used. The repump laser was alternatingly blocked and unblocked with the help of a Thorlabs mechanical shutter controlled by a I/O Box connected to the ANDOR CC-010 PCI card while acquiring image and the difference of the blocked and the unblocked images was being recorded as the signal.

Laser Systems

A grating stabilized diode laser was used for the 866.452nm repump beam. For generation of 396.959nm light, a frequency doubled Ti-sapphire laser was used. The light beams were coupled through single mode fibers to ensure clean circular beams, which was essential for reduction of scattered light inside the trap. During the experiment the Ti-Sapphire laser was manually scanned by 500MHz on both sides of the resonance in 10MHz intervals. For each interval the repump laser was scanned by 400MHz on either side of the transition.

Test setup

For testing purposes, a separate setup was built. A glass T attached to a T-shaped steel chamber having copper feedthroughs at the bottom was used for the purpose. It contained a Ca atom source, identical to the one described earlier. The electron gun consisted of a Rhenium filament held by two stainless steel electrodes over the Ca atom source. The chamber was evacuated to 6E-8 torr. The setup was used for observing fluorescence in Ca^+ ions excited by the 396.959nm laser.

Results and discussions

Till the time of writing this report, we were unable to observe fluorescence with our experimental technique in both the setups. As such we planned for some modifications of our experimental technique. To confirm whether the transition frequency values which we were using are correct or not, we plan to carry out a spectroscopy of Ca^+ ions using a hollow cathode lamp cell. Another modification which may be carried out is locking the repump laser to some transition peak of IBr near 866.452nm and shifting the wavelength appropriately using an AOM. This would eliminate the need of scanning the repump laser.

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