Saturation spectroscopy of calcium atomic vapor in hot quartz cells with cold windows

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Abstract. Saturation spectroscopy of calcium atomic vapor was performed in hot quartz cells with cold windows. The Doppler-free absorption resonances with spectral width near 50 MHz were observed. For these experiments and future applications long-lived quartz cells with buffer gas were designed and made. A cooling laser for calcium magneto-optical trap will be frequency locked to the saturation resonances in the long-lived cells.

1. Introduction
Our research activity is focused on preparation and study of ultracold gases of lithium and calcium Rydberg atoms. In a magneto-optical trap (MOT) a cloud of lithium-7 atoms with temperature $T < 1 \text{ mK}$ [1,2] was trapped. By using two-photon optical excitation the Rydberg states with principal quantum number from 38 to 160 were identified and studied [3–5]. Our theoretical studies of the Rydberg atoms and ultracold plasma were reported in [6,7]. As the first step in our calcium project the Doppler-free absorption spectroscopy of calcium atomic vapor shall be performed. Observations of Doppler-free resonances in calcium on different atomic transitions were reported in [8, 9]. We plan to use the Doppler-free saturation resonance on strong electric dipole transition $4p^2 1P_1$ to $4s^2 1S_0$ ($\lambda = 423 \text{ nm}$) for frequency stabilization of cooling laser in calcium MOT.

2. Experimental setup and results
The laser system from TOPTICA Photonics AG, based on diode laser with frequency doubler, will be applied for optical cooling and trapping of calcium atoms. The laser emission with power 0.7 W can be tuned near wavelength 423 nm of the calcium resonance transition. The laser frequency will be locked to a narrow atomic resonance. For these experiments and future applications we need long-lived cells with hot calcium vapor. Hot calcium vapor at working atomic densities are chemically very active. Closed vacuum cells with a hot calcium vapor and hot windows will be depredated during a quite short time. For observation of Doppler-free absorption resonances in calcium atomic vapor the special hot cells with cold windows are required. On the base of our developments two special quartz cells were made at State Optical Institute. Into the evacuated cells the buffer gas argon was added. The pressure of argon was selected at the level of 0.01 Torr ($p \approx 10^3 \text{ Pa}$). At this pressure of the buffer gas the calcium atoms from the hot cell area can not reach the cold widows and at the same time it is possible to...
observe Doppler-free saturation resonances. In open cells without a buffer gas the metal vapor will condensate on the cold windows. The metal films will appear on the windows and it will be necessarily to remove this films time by time. For example, in [8] an open cell without buffer gas was used for precision spectroscopy of calcium atoms. Due to the condensation of metal calcium on windows the working period of the cell was limited by 15 hours. Our specially designed and made open cells can work without condensation for a long period of time. Similar open cells with lithium vapor are working in our experimental arrangement already four years.

A scheme of our experimental setup for the saturation absorption spectroscopy of calcium vapor in open quartz cell with cold windows is shown in figure 1. External cavity diode laser (ECDL) served as a source of monochromatic optical emission (power 13 mW, wavelength 423 nm, linewidth < 1 MHz). The tunable laser RLT425-50CMG was assembled at Lebedev Physical Institute RAS.

The cell was heated to 800 °C. Output laser beam was split by polarization beam cube (PBC) cube into pump and probe beams. The ratio of probe beam power and pump beam power was of 0.4. The laser frequency was controlled by wavemeter Angstrom and thermostabilized confocal cavity with the free range of 1.5 GHz [10]. The probe beam after the calcium cell was sent to photodetector. The signal from photodetector was fed to oscilloscope.

On the figure 2 the signal from photodetector is presented (black curve) for one of our quartz cell with calcium vapor and buffer gas argon. Maximum of the narrow Doppler-free resonance corresponds to wavelength 423.3736 nm of atomic transition. The red curve on the figure 2 is the transmission resonances of a thermally stabilised Fabry–Perot interferometer (FPI).

In figure 3(a) the selected Doppler-free resonance from figure 2 is presented. The width of the resonance is of 50 MHz. In other calcium cell with buffer gas the width of observed resonance is of 55 MHz.

Also in our laboratory we have assembled a homemade cell by using standard vacuum parts from company MDC. The cell was used for test experiments in order to select optimum working parameters like the cell temperature. In the homemade cell we put piece of metal calcium. Then the cell was evacuated and heated. There was no buffer gas. The observed Doppler-free resonance is shown in figure 3(b). The width is 47 MHz. The difference between resonances in figure 3(a) and figure 3(b) is associated with the buffer gas in the first cell.

![Diagram](image.png)

**Figure 1.** Scheme of the experimental setup: 1—tunable ECDL; 2—confocal cavity; 3—wavemeter; 4—fiber coupler; 5—calcium cell; 6—photodetector; 7—digital storage oscilloscope; 8—polarization beam cube (PBC).
Figure 2. Doppler-free absorption resonance and FPI transmission resonances.

Figure 3. Doppler-free absorption resonances observed in the calcium cell with buffer gas (a) and in the calcium cell without buffer gas (b). The smooth curves are results of the fit by Lorentz functions.

3. Conclusions
We have tested long-lived open quartz cells with calcium vapor and argon gas. The Doppler-free absorption resonances were observed. The cooling laser in the calcium MOT will locked to Doppler-free absorption resonances.
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