

# Preparation of Rydberg states in ultracold Li-7 atoms by using coherent or non-coherent optical excitation

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**Abstract.** Energy spectra of ultracold Rydberg lithium atoms are discussed. Our technique has been used for the experimental observation of coherent and non-coherent components of two-step excitation in Rydberg states. The high sensitivity of the technique has allowed us to record narrow coherent resonance at  $2P-41D$ . The width of this resonance is 3 times less than width of non-coherent resonance. The coherent resonance is observed when the laser is detuned by  $\pm 803.5$  MHz from the atomic transition  $2P_{3/2}$ .

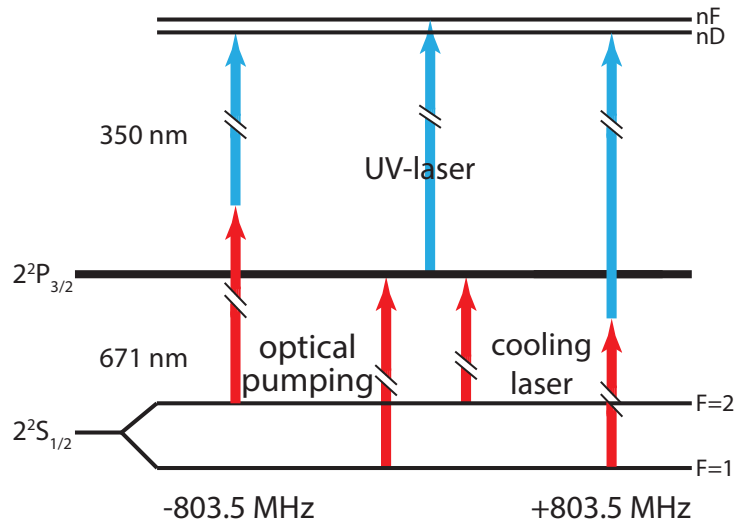
Experimental research of Rydberg lithium atoms [1] is important for fundamental physics and for advanced quantum technologies [2]. The experiments with lithium Rydberg atoms can serve as a model for experiments on creating anti-hydrogen [3,4]. Note that lithium is a chemical element closest in its characteristics to hydrogen.

The standard diagnostic techniques of Rydberg states are based on atomic ionization by an electric field [1]. Recently more convenient diagnostic technique was developed [5]. This technique does not destroy the Rydberg states of atoms. Direct observation of resonance fluorescence of ultracold atoms in a trap with small losses provides high sensitivity.

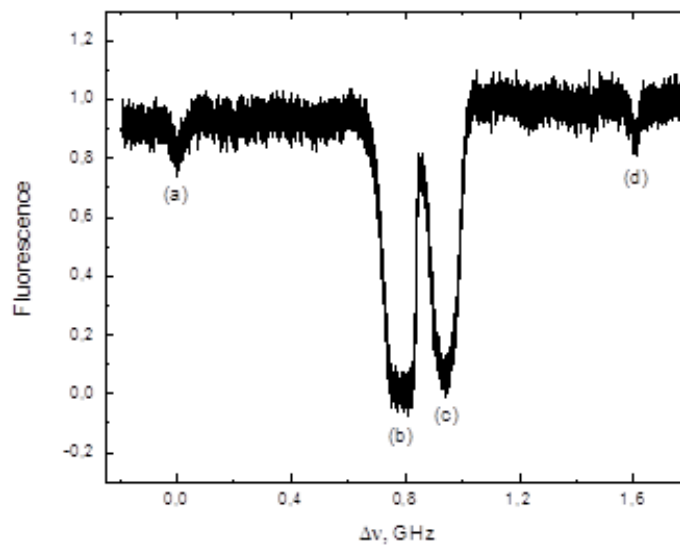
In this paper, the energy spectra of ultracold Rydberg lithium 7 atoms were studied by using our technique which has been described in [5–9]. We observed coherent and non-coherent components of two-step excitation atoms from the ground-state  $2S$  to  $41D$  configurations. The width of the coherent component is 3 times less as compared with the non-coherent component. Coherent excitation allows to increase the accuracy of measurements [10].

Ultracold atoms are cooled and trapped in MOT (magneto-optical trap). For producing Rydberg atoms, we use an ultraviolet (uv) laser (Newport-Spectra Physics). This laser operates on the power up to 100 mW at a wavelength of 350 nm. A width of the emitted radiation spectrum is approximately of several MHz. The uv laser radiation is sent to the cloud of





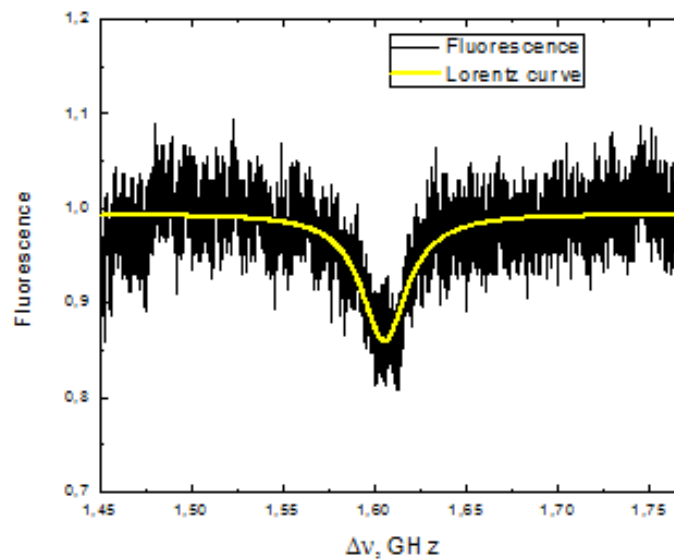
**Figure 1.** Level scheme of a Li-7 atom.



**Figure 2.** Variation of the fluorescence signal: (a) the coherent resonance  $41D$  (uv laser and laser of optical pumping); (b) the non-coherent resonance  $41D$ ; (c) the non-coherent resonance  $41F$ ; (d) the coherent resonance  $41D$  (uv laser and cooling laser). The power of uv beam is 0.01 W.

ultracold atoms located within the MOT. The laser frequency is continuously tuned. The uv laser frequency is controlled by a high-precision wavelength meter with the accuracy 2 MHz [8].

In the experiment we observe the reduction of the fluorescence of the atomic cloud, when the uv laser frequency passes through the Rydberg transition. We use a photodetector for recording of fluorescence signal. We study spectral dependence of the signal near the atomic transition  $2P_{3/2}-41D$ . Level scheme of a Li-7 atom is shown in figure 1.



**Figure 3.** The coherent resonance (d) (uv laser and cooling laser) together with fitting curve.

Two diode lasers with wavelengths 671 nm (optical pumping and cooling lasers) are used in our experiment. Variation of the fluorescence from a cloud of ultracold atoms in the vicinity of the transitions to the state  $n = 41$  is shown in figure 2.

In figure 2, value zero on the vertical axis corresponds to the absence of the fluorescence from the cloud of cold atoms, whereas the unity corresponds to its maximum fluorescence signal from the cloud, when the cloud turns out to be transparent to the uv laser radiation. On the horizontal axis the frequency detuning of uv laser in GHz is shown. In the central part of figure 2 the strongest resonance (b) corresponds to an allowed dipole transition  $2P_{3/2}-41D$ , and the strong resonance (c) corresponds to a forbidden quadrupole transition  $2P_{3/2}-41F$ . These strong resonances are attributed to the non-coherent spectral components. The widths of the non-coherent resonances are above 100 MHz. Weak resonances (a) and (d) in figure 2 are attributed to the coherent components of the two-step excitation  $2S_{1/2}-2P_{3/2}-41D$ . The left resonance (a) is created by the optical pumping laser, and right resonance (d) is created by the cooling laser (see figure 1). The coherent resonances (a) and (d) are shifted from the central non-coherent resonance (b) by the value of the hyperfine splitting of the ground state 803 MHz.

The coherent resonance (d) and the fitting Lorentz curve are presented in figure 3. Using the fit we evaluate the width of the coherent resonance as  $30 \pm 1.1$  MHz. The spectral width of the coherent resonance is three times less than the width of the non-coherent resonance.

By setting up the lasers on the non-coherent resonance, we plan to realize coherent four-wave mixing of optical beams from several lasers in order to record special distribution of the prepared ultracold Rydberg atoms.

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## References

- [1] Gallagher T G 2005 *Rydberg Atoms* (Cambridge: Cambridge Univ. Press)
- [2] Feynman R P 1982 *Int. J. Theor. Phys.* **21** 467–488
- [3] Bobrov A A, Bronin S Y, Manykin E A, Zelener B B, Zelener B V and Khikhlikha D R 2015 *J. Phys.: Conf. Ser.* **653** 012122
- [4] Collaboration T A 2011 *Nature Phys.* **7** 558–564
- [5] Zelener B B, Saakyan S A, Sautenkov V A, Manykin E A, Zelener B V and Fortov V E 2014 *JETP Lett.* **100** 408–412
- [6] Sautenkov V A, Saakyan S A, Vilshanskaya E V, Zelener B B and Zelener B V 2015 *J. Russ. Laser Res.* **36** 119–125
- [7] Saakyan S A, Sautenkov V A, Vilshanskaya E V, Zelener B B and Zelener B V 2015 *J. Phys.: Conf. Ser.* **653** 012123
- [8] Saakyan S A, Sautenkov V A, Vilshanskaya E V, Vasiliev V V, Zelener B B and Zelener B V 2015 *Quantum Electron.* **45** 828
- [9] Zelener B B, Saakyan S A, Sautenkov V A *et al* 2015 *J. Exp. Theor. Phys.* **148** 1086
- [10] Deiglmayr J, Reetz-Lamour M and Amthor T 2006 *Opt. Comm.* **264** 293–298