Absolute Frequency Measurements on the 2S → 3S Transition of ^{7}Li and ^{6}Li*

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Laser spectroscopy plays an important role in the determination of ground state properties of atomic nuclei. Recently this has been again demonstrated by the determination of the nuclear charge radii of the light halo nuclei ^{11}Li [1] and ^{6,8}He [2]. These have been possible thanks to the combination of both, the high resolution of 10^{-5} achieved in the laser spectroscopic isotope shift (IS) measurements and a similar accuracy in atomic theory calculations on the two- and three-electron systems [3]. In the lithium chain, we could provide very accurate numbers for the changes in charge radii between the isotopes. However, absolute charge radius determinations are limited in accuracy by the uncertainty of the reference ^{6,7}Li charge radii, whereas for the helium isotopes the situation is slightly better because the charge radius of ^{4}He is known with higher accuracy. In principle, laser spectroscopy could also be used for a determination of the absolute charge radius as it has been shown in hydrogen [4], provided that the atomic structure calculations of the absolute transition energies can be improved by about an order of magnitude. The calculation of absolute transition energies is still a challenge because of the higher-order mass-independent QED terms, which cancel in isotope shift calculations - since they are mass independent - but contribute fully to the transition energy. Two groups are working on this problem now and try to clearly improve the situation. On the experimental side, transition frequency measurements on these systems are needed with an accuracy of better than about 1 MHz, which is a relative accuracy of a few times 10^{-10}. The recent development of the femto-second frequency comb-device, which links optical and rf frequencies, allows us to determine the transition frequency with the required accuracy.

Therefore, we have measured the $2S \rightarrow 3S$ two-photon transition frequencies of the stable lithium isotopes ^{6,7}Li applying the setup that has been used previously to measure the lithium IS [5] with a laser system that has been adapted for this task. The main modification was that the Titanium-Sapphire (Ti:Sa) laser, which drives the two-photon transition, was phase-locked to a femto-second frequency comb [6] instead of being referenced to an iodine line as previously. Changing the repetition rate of the comb allowed us to sweep the Ti:Sa laser frequency across the resonance line, as it is shown in Fig. 1a. The absolute transition frequency has to be taken as the center of gravity (cg) of the hyperfine components.

Systematics effects, like AC Stark shifts (see Fig. 1b) were studied experimentally. Particularly it was noticed that recorded spectra at high power showed an asymmetry in the line profile that can clearly be observed in Fig. 2a. To understand the profile, simulations were performed that included the lithium atoms crossing through a Gaussian laser field distribution with intensity fluctuations such as they were typical during the experiment. The calculated points shown in Fig. 2 were then fitted with a Lorentzian line profile and the residuals, plotted underneath the peak structure, show a very similar behavior for the fitting of the real as well as of the simulated peaks.

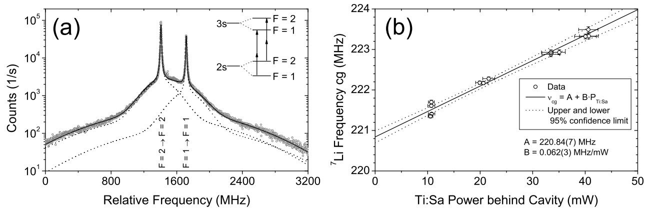

Figure 1: (a) Line shape of the $2S \rightarrow 3S$ atomic transition in ^{7}Li. (b) An AC Stark shift measurement with extrapolation to zero laser intensity.

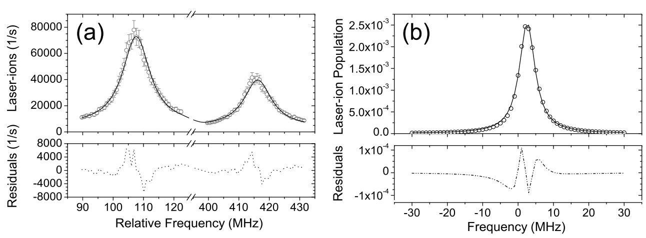

Figure 2: (a) Line profile in the real transition. (b) A simulation reproduces the observed asymmetry quite well.

Final analysis is still ongoing but we expect to improve the accuracy in the transition frequency by about an order of magnitude. Once theory will make the required progress, the absolute field shift contribution in the transition and therefore the total nuclear charge radius could be extracted by pure optical means.

References

[1] R. Sánchez *et al.*, PRL **96**, 033002 (2006).

[2] P. Müller *et al.*, PRL **99**, 252501 (2007).

[3] G. W. F. Drake *et al.* Lect. Notes Phys. **745**, 131 (2008).

[4] T. Udem *et al.* PRL **79**, 2646 (1997).

[5] G. Ewald *et al.*, PRL **93**, 113002 (2004).

[6] http://www.menlosystems.com/fc1500.html

* Work supported by HGF under contract VH-NG-148 and by BMBF under contracts 06MZ215/TP6 and 06TU263I.