Precision spectroscopy on the $2\,^3S \rightarrow 2\,^1S$ transition in ultracold helium inside a magic wavelength trap

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Atomic level energies experience minute shifts caused by the finite size of the nucleus. When this shift was measured in muonic hydrogen a 5σ discrepancy was found with the then most recent CODATA recommended value for the proton radius [1]. Since then this discrepancy has only increased and has been extended to the deuteron as well [2]. The discrepancy has become known as the proton radius problem. Does this problem exist for other atoms as well? To answer this question new measurements on the helium nucleus, both in muonic and electronic systems, are underway. We are aiming for an improved measurement of the doubly forbidden $2^3S \rightarrow 2^1S$ transition in neutral helium. By combining frequency metrology with ab initio QED calculations the ^{3}He to ^{4}He nuclear charge radius difference can be determined with sub-attometer accuracy, competitive with current measurements in muonic He$^+$ [3].

In order to reach this goal we need to improve our previous measurement, which was done in a Bose-Einstein condensate of ^{4}He and a degenerate Fermi gas of ^{3}He trapped in a 1557 nm optical dipole trap (ODT) and was accurate to 2.3 kHz [4], by an order of magnitude. To entirely eliminate the largest term in the uncertainty budget, the ac-Stark shift induced by the ODT, we have implemented a magic wavelength ODT.

Previously, we calculated polarizabilities of the $2\,^3S$ and $2\,^1S$ levels and found a magic wavelength candidate at 319.815 nm [5]. We built a laser system at this wavelength, producing over 2 W of power, and used it to trap ^{4}He atoms [6]. Currently, we have implemented a full ODT with this laser system and are using it for spectrosopy. By varying the wavelength of the laser we have now verified our calculations within their accuracy and we have found the precise position of the magic wavelength at 319.816 nm, accurate enough that the uncertainty in the Stark shift is no longer significant compared to other errors. Finally, we have made a number of other improvements to the set-up and measurement scheme to better deal with other systematics, most notably an improved linewidth of the spectroscopy laser to better deal with the mean-field shift [7] and we hope to present a more accurate determation of the transition frequency in ^{4}He at the conference.

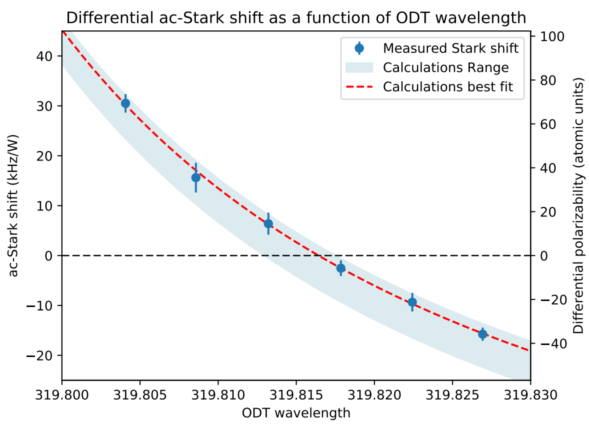

Fig. 1: (Preliminary) ac-Stark shift as a function of trap laser wavelength. The blue band is the calculated differential polarizability from reference [5] with its uncertainty range (rescaled to the data). The leading uncertainty in this calculation is a constant offset caused by the continuum contribution to the polarizability. The dashed line is the calculation with this offset fitted to the data.

References

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