Abstract

Precision spectroscopy of light atomic systems allows the sizes of nuclei to be probed with high accuracy. Surprisingly, different experiments of this type in the hydrogen atom have yielded conflicting results, a problem that has since become known as the proton radius puzzle.

The work described in this thesis seeks to probe the size of the helium nucleus instead, using helium atoms in the metastable state. To achieve this goal, small atomic ensembles are laser cooled to less than a microkelvin above absolute zero and trapped in the focus of an intense laser beam. By carefully tuning the wavelength of the trapping laser to a so-called magic wavelength, the distorting influence of the trap laser on the spectroscopy measurement can be canceled. By performing ab initio calculations of the atomic polarizability, a promising magic wavelength is found in the ultraviolet part of the spectrum and a powerful laser system is constructed to operate a trap at this wavelength. Using this trap, the frequency of radiation required to drive an exceedingly weak transition is measured with extreme accuracy. Thus the single most accurate spectroscopic measurement in the helium atom to date is realized, probing the size of its nucleus at sub-attometer precision.