High Precision Atomic Data as a Measurement Tool for Halo Nuclei: Theory

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Abstract. Halo nuclei were first discovered by Tanihata in 1987. They are a form of atomic nucleus having a halo of excess planetary neutrons surrounding a tightly bound core. The atomic isotope shift method is now well established as the only effective method to determine their nuclear charge radius. The method depends on a comparison between theory and experiment for high-precision laser resonance measurements of atomic transition frequencies. Accuracies at the level of ±10 kHz are required for both theory and experiment. Three broad series of measurements are now available for light nuclei, extending all the way from ^{3}He to the halo nuclei ^{6}He and ^{8}He, ^{6}Li to the halo nucleus ^{11}Li, and ^{7}Be to the single-neutron halo nucleus ^{11}Be. The results are particularly significant because they are able to discriminate amongst various theoretical models for the effective interaction potential between nucleons. By studying systems that fall apart easily, we learn about the forces holding them together. The principle of the method will be discussed in terms of the atomic structure calculations that are required to extract the nuclear charge radius from the isotope shift. The principal theoretical challenges are (a) to obtain sufficient accuracy in the lowest order nonrelativistic and relativistic contributions to the isotope shift, and (b) to calculate the mass dependence of the higher-order QED contributions, such as the Lamb shift. The current status of theory will be reviewed, and compared with experiment, as discussed in the companion paper by W. Nördershäuser. In view of the recently announced discrepancy in the proton radius, a comparison between muonic and electronic helium becomes particularly relevant and interesting.