Nuclear Sizes and Isotopic Shift

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We study the charge radii of exotic nuclei through nuclear calculations and by non-perturbative isotopic-shift (IS) evaluations. Beside nuclear masses (or binding energies), nuclear charge radii, spins, and nuclear moments are informations on ground state properties of atomic nuclei. The latter can be obtained by atomic spectroscopy. In fact, most information on the static properties of exotic systems have been determined in this way [1]. For a given electronic transition, the IS is the sum of: A) the mass shift (MS) originating from the finite mass of the nucleus and the electron-electron correlation, and B) the field shift (FS) that reflects the differences in the nuclear charge distributions. Although the information on nuclear ground-state properties extracted from a study of hyperfine structure and isotope shift is model-independent, it is hampered in complex neutral atoms by the accuracy with which the electron wave functions are known at the site of the nucleus. However, in the case of simple few-electron systems the electron wave function can be precisely calculated. Recent advances in variational calculations for lithium and lithium-like ions using multiple basis set in Hylleraas coordinates [2], made possible to calculate the MS in the 2S-3S and 2S-2P transitions of lithium with a very good accuracy. Therefore, if the overall isotopic shift can be measured with a comparable precision, the rms charge radius can be extracted. Accordingly [2], the charge radius of the isotopes is given by:

$$\delta(IS)_{exp} = \delta(MS)_{the} + \frac{2\pi Z}{3}\delta|\psi(0)|^2\delta < r^2 > \qquad (1)$$

In this way, absolute charge radii can be determined. Furthermore, in combination with measurements of the matter radius, neutron radii can be extracted. For the future, experiments on stable and long-lived lithium-like ions up to uranium are planned at the ESR and NESR. This requires the availability of a reliable soft-x-ray laser, which was recently demonstrated at PHELIX [3]. A recent experiment on radioactive lithium isotopes [4], aiming for a determination of the charge and the neutron radius of ^{11}Li, provides an excellent example for a test of nuclear and atomic theories. Our nuclear computations of the charge radius are performed in the framework of the dynamic-correlation model DCM for nuclei with an odd number of valence particles, and in the boson dynamic-correlation model (BCDM) for those with an even number of valence particles [5]. These nuclear models take fully into consideration the correlation between valence particles as well as between valence and core particles. Consequently, these computations may reveal feature physics which is associated to the strong correlation between the valence and the core polarized states. Moreover, we propose to test the derived charge radii within the isotopic shift theory in which the electronic transitions for lithium and lithium-like ions are calculated by considering the three correlated electrons described by a model similar to the nuclear DCM. Within this nonlinear and non-perturbative model, the treatment of the halo of the proton distribution can be performed self-consistently. The proposed theoretical method is applied to two specific problems: a) high-resolution isotope shift calculation on unstable lithium isotopes, and b) measurement of the 2p-2s transition in lithium-like uranium. In both ranges of isotopes is performed non-perturbative IS calculation which is appropriate for calculating charge radii in halo- and exotic nuclei. Nuclear-model-independent rms charge radii can be then obtained from IS calculations. The IS is evaluated as in [6] in terms of the rms radius using an electron distribution calculated selfconsistently. At this stage of the calculation, in order to test from one side the non perturbative electron dynamic-correlation model (eDCM) presented in Ref. [7] and from the other side the charge radii as derived from the charge distributions [8], we propose to insert these calculated values in Eq. 1. The calculated MS and the theoretical charge radii should then reproduce the experimental IS.

Preliminary results calculated using eDCM for the electron space are given in table 1. One example is the binding energy in the atomic lithium system without nuclear corrections, the other the 2s-2p transition energy in lithium-like $^{235}U^{91+}$.

Energies in lithium (au)	$1s^2 2s$
Drake [9]	-7.47806032310 (31)
eDCM this work	-7.478060733
Transitions in $^{235}U^{91+}$ (eV)	2s-2p
Yerokhin [10]	288.44(20)
eDCM this work	288.33

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