Precision Laser Spectroscopy of Beryllium*

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The neutron-rich beryllium isotopes exhibit a halo structure. The matter distribution of such isotopes is significantly larger than that of their neighbor isotopes due to a very low-density tail in the matter distribution. Important information about the nuclear structure of a halo nucleus can be obtained by measuring its nuclear charge radius, i.e. the size of the proton distribution. The difference in mean-square nuclear charge radii between two isotopes $\langle r^2\rangle_A, \langle r^2\rangle_{A'}$ is related to the isotope shift (IS) of an atomic transition as follows

$$\langle r^2\rangle_A - \langle r^2\rangle_{A'} = (\mathrm{IS} - \mathrm{MS})/C_{\mathrm{FS}}. \qquad (1)$$

For light elements, like beryllium, the mass shift (MS) has to be calculated together with the field shift constant (C_{FS}) at least with a relative accuracy of 10^{-5}. It is also required to measure the IS at the same level of accuracy.

We have recently performed high-resolution collinear laser spectroscopy on a fast beryllium ion-beam and measured the IS in the $2\,\mathrm{S}_{1/2} \rightarrow 2\,\mathrm{P}_{1/2}$ (D_1) and $2\,\mathrm{S}_{1/2} \rightarrow 2\,\mathrm{P}_{3/2}$ (D_2) transitions of $^{7,10,11}\mathrm{Be}^+$ with respect to $^{9}\mathrm{Be}^+$. Here, we present the results of IS measurements in the D_2 transition and extracted charge radii. The complete laser system was built and tested at GSI and Mainz University. The measurements were performed at the radioactive beam facility ISOLDE at CERN. The beryllium isotopes were laser ionized, mass separated, accelerated and delivered to the collinear beamline COLLAPS. The ions were overlapped with two laser beams, one of them propagating in the beamline collinearly and the other anticollinearly to the ion beam. The lasers were frequency stabilized to an iodine transition and to a frequency comb, respectively. Scanning across the resonances was performed with the so called Doppler tuning. More details about the experiment are reported in [1, 2]. The absolute transition frequency (ν_0) was determined from the centers of gravity ν_c and ν_a in the collinear and anticollinear spectrum, respectively, according to $\nu_0 = \sqrt{\nu_c \times \nu_a}$. The centers of gravity were calculated from the individual peak centers and the corresponding hyperfine splitting and a relative accuracy of 2×10^{-9} was reached. IS were extracted from the difference in absolute transition frequency of two isotopes. The final charge radii of 2.637(55), 2.339(53) and 2.463(62) fm for $^{7,10,11}\mathrm{Be}$ [2] were determined using mass shift calculations [4, 5], field shift constant calculations [4, 5] and reference charge radius $r_c(^{9}\mathrm{Be})$=2.519(12) fm obtained from electron scattering. As depicted in figure 1, the charge radii from the D2 line are in a very good agreement with the charge radii obtained from the D_1 line [1], but with larger uncertainties due to the unresolved hyperfine structure in the $\mathrm{P}_{3/2}$ state. The experimental data are compared to nuclear calculations and the trend of charge radii is well reproduced, especially from new Fermionic Molecular Dynamics calculations [2]. The charge radii are decreasing from ^{7}Be to ^{10}Be which is assigned to clustering. A significant increase between ^{10}Be and ^{11}Be is mainly due to the halo neutron which moves the ^{10}Be core around the center of mass. According to the comparison with fragmentation experiments and the nuclear calculations, core polarization contributions are expected to be very small. From the IS in the D_1 and D_2 transitions we extracted splitting isotope shifts of -5.1(2.2), 3.5(2.4) and 3.6(2.5) MHz for ^{7,10,11}Be, respectively. These are consistent with theoretical calculations [5, 4] and provide a valuable check of the beryllium experiment.

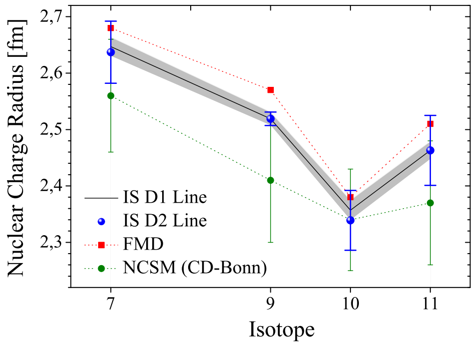

Figure 1: Experimental charge radii from the isotope shift measurements D1 line [1] (grey area indicates the uncertainties) and D2 line [2] compared with theoretical predictions from Fermionic Molecular Dynamics [2] and No Core Shell Model with the CD-Bonn potential [3].

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