Measurement of the Two-electron Contribution to the Ground State Binding Energy in He-like Uranium

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Study of spectra of helium-like ions has proven to be useful for understanding relativistic, correlation and QED effects in many-body systems. Recently, there has been a significant progress in theoretical as well as experimental studies of such systems, in particular for the high-Z regime. Various theoretical investigations based on different methods such as the relativistic many-body perturbation theory (RMBPT) [1], multi configuration Dirac-Fock [2] and the unified method [3], have been performed. For the ground state the progress is in particular impressive, since even the two-electron QED contributions have been evaluated completely up to the second order [4, 5]. Experimentally a new approach has been developed which exploits radiative recombination (RR) transitions and provides a direct access to the two-electron contribution for the ground state in He-like systems [6, 7]. All one-electron contributions to the binding energy such as finite-nuclear size corrections and the one-electron self energy cancel out completely in this type of experiment. Note, this is a distinctive feature of this particular kind of QED test and is in contrast to all other tests of bound state QED for high-Z ions such as $1s$ Lamb shift (in one-electron systems), g-factor of bound electrons, or hyperfine splitting.

Recently, we carried out an experiment for an investigation of the two-electron contributions to the ground state binding energy in helium-like uranium at the electron cooler of the ESR storage ring. For the details of the experiment please refer to the [8]. A very important aspect of our study was a precise determination of the X-ray energies. Although the intrinsic resolution of the Ge(i) detector (used in the experiment) for the energy range of relevance is about 750 eV, small energy difference between two close spaced lines can be determined with high accuracy [9]. In order to take advantage of this property, the projectile energy of 43.59 MeV/u was chosen. At this particular beam energy the Doppler shift close to 0^o allowed us to park the 177.2 keV γ-line of ^{169}Yb, used for calibration, just in between the K-RR lines for H-, and He-like uranium. During the experiment the calibration source was regularly placed in front of the detector in order to gain control over possible drifts. During the data analysis the calibration behavior as a function of time was analyzed. The data were divided into individual groups and were analyzed separately. After this, results deduced from each of the individual data sets were compared and checked for consistency. At the end, by combining all the individual data sets, the final result of 2248 ± 9 eV was obtained. In order to elucidate in more detail the achieved experimental sensitivity, we compare in table 1 our result with the individual two-electron contributions as calculated in [4]. Our result agrees with the theoretical prediction within the experimental uncertainty. In the context of RMBPT, our uncertainty is smaller than the second-order many body contribution so the experimental result is sensitive to this part of the theory. Moreover, our accuracy is of the same size as the second-order two-electron self energy contribution. Here, we would like to stress that in our experiment contribution of possible systematic error sources are essentially eliminated and our result is only limited by counting statistics.

1^{st} order RMBPT	2^{nd} order RMBPT	$\geq 2^{nd}$ order RMBPT	NR
2265.87	-14.16	0.05	1.3
2eSE	**2eVP**	**Total theory**	**Exp.**
-9.7	2.6	2246.0	2248 ± 9

Table 1: Comparison of our experimental result with the RMBPT calculations of Persson [4]. NR: non-radiative QED; 2eVP: two-electron vacuum polarization; 2eSE: two-electron self energy (all values in eV).

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