The Ground-State Lamb Shift in H-like Uranium

A. Gumberidze[1,2], Th. Stöhlker[1,2], D. Banaś[1,3], G. Bednarz[4], H. F. Beyer[1], F. Bosch[1], X. Cai[5], S. Hagmann[1,2], O. Klepper[1], C. Kozhuharov[1], D. Liesen[1], X. Ma[1,5], P. H. Mokler[1,6], A. Oršić Muthig[1,2], D. Sierpowski[4], Z. Stachura[7], M. Steck[1], S. Tashenov[1,2], S. Toleikis[1], A. Warczak[4] and Y. Zou[8]

[1]GSI, Darmstadt, Germany; [2]IKF, Univ. of Frankfurt, Germany; [3]Institute of Physics, Świętokrzyska Academy, Kielce, Poland; [4]Jagiellonian University, Krakow, Poland; [5]Institute of Modern Physics, Lanzhou, China; [6]University of Gießen, Germany; [7]INP, Cracow, Poland; [8]Fudan University, Shanghai, China

Despite the enormous success of QED in predicting the properties of electrons in weak fields [1, 2], a precise test in the strong-field limit where novel phenomena might show up, is still pending. Thus, a primary goal of atomic structure studies at high-Z is to explore the behavior of electrons in the strongest electromagnetic fields accessible to experimental investigation. Precision measurements of electron binding energies are best suited to deduce characteristic QED phenomena in strong fields and a comparison of predicted with experimentally determined level energies provides a critical test of the theory in this regime [3, 4].

Until recently the largest sources of theoretical uncertainties in predicting the binding energies for high-Z one-electron systems were unevaluated higher order QED contributions [5, 6]. During the last few years significant progress took place in this direction resulting in a completion of calculations of the all second order (in α) QED corrections without an expansion in the parameter αZ [7, 8]. For uranium these corrections are of the order of 1 eV; thus providing the experiment with a challenge to achieve a precision of 1 eV or better. For such systems, the most direct experimental approach for the investigation of the effects of QED in strong Coulomb fields is a precise determination of x-ray energies emitted by transitions from bound (and/or continuum) states into the ground state of the ion. Within the last years there has been a constant increase of the maximum possible number of stored ions in the ESR. This is a very important prerequisite for achieving a higher experimental precision; due to an improvement in statistics which in turn allows the experiments to be conducted in much shorter periods of time, thus reducing possible systematic uncertainties as well. Although the ESR provides brilliant, monochromatic beams, the main problem encountered is still caused by the uncertainties introduced from the Doppler shift, because the x-rays are emitted by ions moving with relativistic velocities [9, 10]. Besides statistics, errors introduced by these corrections limit the final accuracy of the x-ray energy in the emitter frame. However, a significant reduction of these uncertainties can be achieved by exploiting a 0^o geometry and/or a deceleration of the ion beam. We have combined these two techniques at the electron cooler of the ESR storage ring in order to determine the ground state Lamb shift in hydrogenlike uranium with high accuracy. Details of the experiment can be found in [11]. The value for the 1s Lamb shift was deduced by precise determination of energies of x-rays emitted via characteristic and radiative recombination transitions. For this purpose, three independent strips of a segmented germanium detector were used. The energies of the transition lines were always determined relative to the closely spaced calibration γ-ray lines of ^{169}Yb. The calibration was performed regularly in order to gain control over possible systematic drifts. The data were subdivided into individual groups, analyzed separately and checked for consistency. At the end, combining results from all the individual data groups a value of 459.8±4.8 eV was obtained for a ground state Lamb shift in hydrogenlike uranium. The quoted error comprises together with a statistical uncertainty in line centroid determination, an error introduced by the Doppler corrections of 3.5 eV and represents an improvement by a factor of 3 as compared to the most precise value up to now [9]. In the table we compare our result for the 1s Lamb shift with the newest theoretical value [8]. Some individual contributions to the total theoretical Lamb shift are listed separately as well. From the comparison, we can state that our result provides a test of the first order (in α) QED corrections at the 2% level and only a slight improvement is required in order to achieve a sensitivity to the contributions of higher-order.

Finite nuclear size	198.81
1-st order QED	266.45
2-nd order QED	1.57(31)
Total Lamb shift [8]	464.26±0.5
Experiment	459.8±4.8

Table 1: The Ground-state Lamb shift in H-like uranium.

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