# The Effect of the Breit-Interaction Studied for the Emission Characteristics of $1s2s^22p_{1/2}$ Decay in Be-like Uranium *

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The well-known Breit interaction was first worked out by Gregory Breit in order to calculate the fine-structure of atomic helium [1]. Nowadays, the Breit interaction is described as quantum electrodynamics (QED) effect. It includes magnetic interactions and retardation in the exchange of a single virtual photon between the electrons, and affects not only the energy level structure but also the dynamics of atomic processes. The interaction has aroused great interest in further exploration and analysis of relativistic contributions to the electron-electron interaction, and its importance has already been confirmed for several processes in the collisions between electrons and highly charged ions (HCI) [2, 3, 4, 5, 6, 7, 8, 9].

More often than not the influence of the Breit interaction is small, so it is treated as a minor correction to the Coulomb interaction. However, in certain cases it can even dominate dynamics involving highly charged ions. Nakamura et al. [10] found that the Breit interaction can enhance dielectronic recombination (DR) resonant strengths by almost 100%. Soon afterwards, Fritzsche et al. [11] predicted that the Breit interaction could dominate the Coulomb interaction in the x-ray emission of Li-like heavy ions following dielectronic recombination and could even qualitatively change the angular distribution of x-rays for heavy ions with nuclear charge $Z \geq 73$. Three years later, Hu et al. [12] obtained experimental evidence for the prediction of Fritzsche et al. by measuring the angular distribution of the $[1s2s^22p_{1/2}]_1 \rightarrow [1s^22s^2]_0$ transition in dielectronic recombination of Li-like Au with free electrons in an electron beam ion trap (EBIT).

In this report, we present the experimental results for angular distribution of characteristic x-rays following the resonant transfer and excitation (RTE) in $U^{89+}$ collisions with $H_2$ target at the experimental storage ring ESR of GSI. The RTE is equivalent to the DR processes, but with the difference that the electron is initially in a bound state of target. The experiment performed by colliding Li-like uranium ($U^{89+}$) ions with $H_2$ at the resonance energy (116.15 MeV/u) for the $U^{89+}[1s^22s] \xrightarrow{H_2} U^{88+}[1s2s^22p_{1/2}]_1$ process. The accurate and stable value of the ion beam energy was guaranteed by the electron cooler of the ESR. The layout of the experimental arrangement at the gas-jet target is shown in Fig. 1. We measured the angular distribution of the $[1s2s^22p_{1/2}]_1 \rightarrow [1s^22s^2]_0$ x-ray transition following the resonant transfer and excitation.

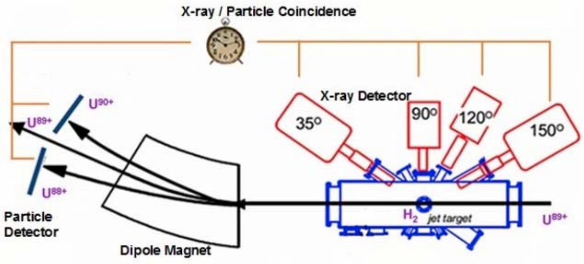

Figure 1: The experimental setup at the internal gas-jet target of the ESR.

The x-ray emission from the collisions was recorded with four high purity intrinsic germanium (HPGe(i)) detectors placed at $35^0$, $90^0$, $120^0$ and $150^0$ angles with regard to the direction of the ion beam. Exploiting time coincidences between the x-ray detectors and a particle detector mounted after the ESR dipole magnet, we were able to obtain the x-ray spectra corresponding only to the events of $U^{89+}$ capturing an electron into singly or doubly excited states.

Four x-ray spectra have been obtained in the experiment at $35^0$, $90^0$, $120^0$ and $150^0$ observation angles corresponding to one-electron-capture events. As an example, Fig. 2 shows the spectrum recorded at $35^0$ angle. In the spectrum, several radiative electron capture (REC) lines are present. They are denoted according to the shell where the target electron is captured into, i.e. L-REC stands for the capture into the L-shell (n=2), M-REC stands for the capture into the M-shell (n=3), etc. In addition, the RTE induced peak ($[1s2s^22p_{1/2}]_1 \rightarrow [1s^22s^2]_0$ transition) very close to the radiative electron capture into the $2s_{j=1/2}$ and $2p_{j=1/2}$ states (L-REC$_{1/2}$) is found. The REC peaks are significantly broader than the RTE-induced characteristic transition, due to the Compton profile of the target. This allows us to fit the RTE and REC lines separately and obtain the corresponding intensities. This is also possible for x-ray spectrum recorded at $150^0$. However, at $90^0$ and $120^0$, the large Doppler broadening and a poorer energy resolution

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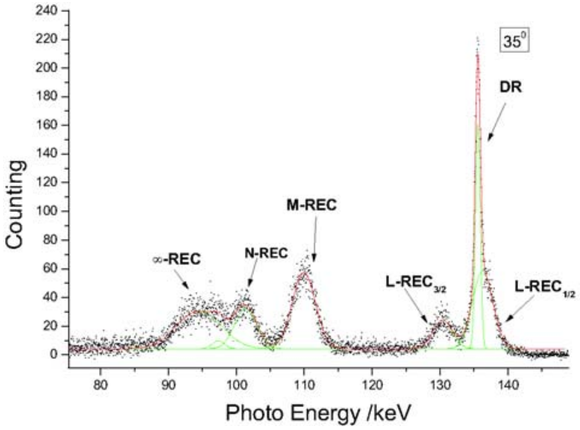

Figure 2: X-ray spectrum obtained at the ESR corresponding to one-electron-capture events in 116.15 MeV/u $U^{89+}$ collisions with the $H_2$ gas target, obtained at $35^0$ observation angle.

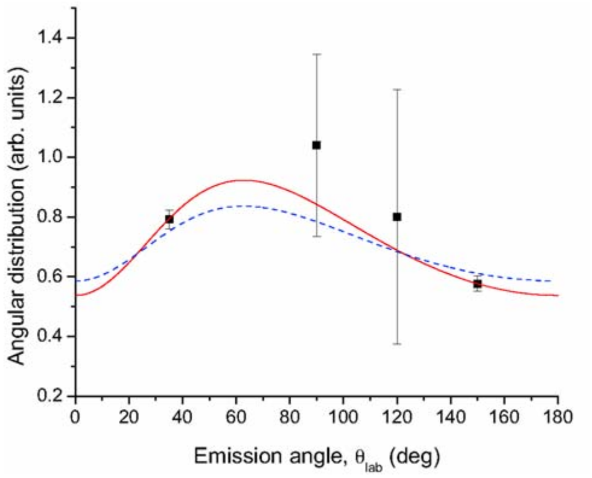

Figure 3: Experimental angular distribution for the $[1s2s^22p_{1/2}]_1 \rightarrow [1s^22s^2]_0$ transition following the RTE into initially Li-like uranium. The dashed line is a theoretical angular distribution from [11], with the alignment parameter $A_2$= -0.314. The solid line is from fitting the equation of the electric dipole emission [11] to our experimental data, having $A_2$ as a free fit parameter.

of the corresponding detectors smear out the difference between the RTE and L-REC$_{1/2}$ peaks, making it impossible to fit them separately and obtain directly their intensities. Therefore, we have to rely on the relativistic REC theory which has been extensively tested in many different experiments [13] and is currently known to provide accurate description of the process. Namely, we used the angular differential cross sections for L-REC$_{3/2}$, L-REC$_{1/2}$ and M-REC [14] together with our experimental data for obtaining the intensity of the L-REC$_{1/2}$. As a cross check of theory, we also compared the theoretical values with our experimental results for L-REC$_{1/2}$ : L-REC$_{3/2}$ and L-REC : M-REC ratios at $35^0$ and $150^0$ where we could obtain the experimental values independently from the theory. We found a fair agreement between the theoretical and experimental results, however, in couple of cases a deviation of about 10% has been observed. The reason of this deviation is currently unclear. Therefore, we included the uncertainty of 10% for obtaining the experimental RTE intensity values at $90^0$ and $120^0$ angles. Furthermore, in order to obtain the angular distribution of the RTE induced $[1s2s^22p_{1/2}]_1 \rightarrow [1s^22s^2]_0$ transition, we normalized its intensity to the one of the closely spaced L-REC$_{3/2}$ peak and used the theoretical angular differential cross-section for the latter. In this way, uncertainties related to different solid angles and efficiencies of the x-ray detectors are almost completely cancelled out.

Our experimental and theoretical angular distributions [11] of the $[1s2s^22p_{1/2}]_1 \rightarrow [1s^22s^2]_0$ transition are shown in Fig. 3. From the figure, a good qualitative agreement between the experiment and theory agreement can be observed. By fitting the equation for angular distribution of the electric dipole emission [11] to the experimental angular distribution, we received the experimental value for alignment parameter $A_2 = -0.46 \pm 0.07$. Our result is definitely closer to the prediction from [11] with Breit interaction included (-0.314) than to the one without the Breit interaction (0.47). This can be considered as a proof for the high importance of the Breit interaction for this case. The reason for the relatively small ($\sim 2\sigma$) quantitative deviation between our experimental and theoretical results for the alignment parameter ($A_2$) has still to be clarified.

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