Magnetic interactions and retardation in the electron emission from highly-charged ions

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X-ray studies from multiple and highly charged ions have been found a unique tool for exploring the electron-electron (e-e) and electron-photon interactions in the presence of strong fields [1]. The x-ray spectroscopy of such systems have demonstrated for a long time that accurate energies and cross sections are obtained only if, apart from the static Coulomb repulsion among the electrons, the magnetic interactions and retardation as well as leading quantum-electrodynamical effects are taken into account. In contrast to the spectrocopy of hard x-rays, however, much less is known how relativistic interactions among the electrons affect their emission and, hence, the dynamics of electrons in strong fields.

To obtain further insight into the strong-field dynamics of electrons, we re-analyzed the excitation and autoionization of highly charged ions with the goal to separate the magnetic and retardation contributions to the e-e interaction from the static Coulomb repulsion. A remarkable change in the electron angular distribution due to the relativistic terms in the e-e interaction was found especially for the autoionization of (initially) beryllium-like projectiles, following a $1s \rightarrow 2p_{3/2}$ Coulomb excitation in collision with some target nuclei. In this process, the angular distribution of the emitted electron is given by

$$W(\theta) \propto 1 + \sum_{k=2,4,\ldots} \mathcal{A}_k(\alpha_r J_r)\, f_k(\alpha_r J_r, \alpha_f J_f)\, P_k(\cos\theta),$$

where $\mathcal{A}_k(\alpha_r J_r)$ characterizes the alignment of the intermediate state after the excitation, θ is the polar angle with regard to the beam direction and where the $f_k(\alpha_r J_r, \alpha_f J_f)$ are characteristic functions that describe the dynamics of the autoionization. The function f_k in this distribution merely depends on the (reduced) matrix elements of the (frequency-dependent) e-e interaction

$$V = V^{\rm Coulomb} + V^{\rm Breit}$$

that comprises both, the instantaneous Coloumb repulsion and the (so-called) Breit interaction, i.e. the magnetic and retardation contributions.

For the excitation-autoionization process via the $1s2s^22p_{3/2}\ ^3P_2$ resonance, a diminished (electron) emission in forward direction as well as oscillations in the electron angular distribution due to the magnetic and retarded interactions are predicted especially for the electron emission into the $1s^22s\ ^2S_{1/2}$ ground and $1s^22p\ ^2P_{1/2}$ excited levels of the finally lithium-like ions. This emission pattern is in strong contrast to a pure Coulomb repulsion between the bound and the outgoing electrons. For example, Figure 1 displays the angular distribution of electrons emitted in the $1s2s^22p_{3/2}\ ^3P_2 - 1s^22s\ ^2S_{1/2}$ (left panel) and $1s2s^22p_{3/2}\ ^3P_2 - 1s^22p\ ^2P_{1/2}$ (right panel) autoionization of U^{88+} projectiles with energy T_p = 5 MeV/u. Results are shown in the laboratory frame and by incorporating only the Coulomb repulsion into the Auger amplitude (blue dashed lines) as well as for a full account of the e-e interaction (black solid lines). The lowering of the electron emission in forward direction ($\theta \approx 0^o$) is significant and enhanced in the laboratory frame due to the Lorentz transformation of the energetic electrons

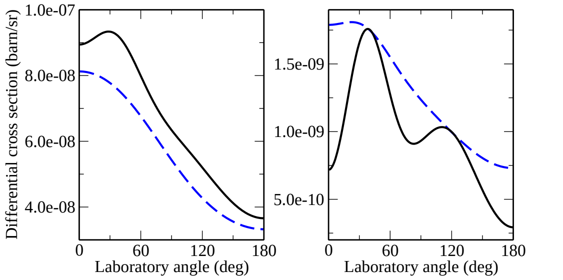

Figure 1: Angular distribution of electrons emitted in the $1s2s^22p_{3/2}\ ^3P_2 - 1s^22s\ ^2S_{1/2}$ (left panel) and $1s2s^22p_{3/2}\ ^3P_2 - 1s^22p\ ^2P_{1/2}$ (right panel) autoionization of U^{88+} projectiles with energy T_p = 5 MeV/u.

In conclusion, the proposed excitation-autoionization process can be observed at existing storage rings and will provide novel insight into the dynamics of electrons in strong fields. The most simple signatures of the relativistic contributions to the e-e interaction in high-Z ions is the reduced electron emission in forward direction ($\theta < 5^o$) as well as the double-peak structure in the expected angular distribution; these signatures arise especially at low projectile energies $<$ 10 MeV/u and for beryllium-like ions with nuclear charge $Z > 70$. The electron angular distribution from such projectiles can be analyzed with present-day electron spectrometers and provide complementary information about the electron dynamics in strong fields that is not accessible from x-ray spectra alone.

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References

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