Resonant Transfer and Excitation for H- and He-like U-Ions

Zoltán Harman, Stephan Zakowicz, Matthias Gail, Norbert Grün, Werner Scheid
Institut für Theoretische Physik, Justus-Liebig-Universität Giessen

We present calculations for the angular distribution of photons emitted after KLL-RTE (Resonant Transfer and Excitation) in collisions of U^{91+}- and U^{90+}-ions with hydrogen atoms. Measurements with H-like projectiles were recently performed by Ma et al. at GSI and are currently being evaluated [1]. In the past, a similar process has been studied both experimentally [2] and theoretically [3], in which graphite was used as target. However, the width of the Compton profile of the electron bound in the H-atom is smaller than in graphite, resulting in a better resolution of the resonance groups in the cross sections.

The electron bound in the hydrogen atom can be regarded as quasifree. Therefore, the RTE cross section can be calculated by using the cross section of dielectronic recombination (DR). In DR, a free electron is captured by the projectile with the simultaneous excitation of a bound electron, followed by the emission of a photon. Doubly-excited states embedded in the one electron continuum give rise to resonances in the cross sections. With perturbation theory we obtain the following expression for the differential cross section in the rest frame of the projectile ion:

$$\begin{aligned}\frac{d\sigma^{DR}_{i\to d\to f}}{d\Omega_k} &= \frac{2\pi}{F_i}\frac{1}{2(2J_i+1)}\sum_{M_f\lambda}\sum_{M_d}\sum_{M_i m_s} \\ &\quad |\langle\Psi_d;J_dM_d|V_{capt.}|\Psi_i;J_iM_i,p_em_s\rangle|^2 \\ &\quad \times\frac{|\langle\Psi_f;J_fM_f,\mathbf{k}\lambda|H_{er}|\Psi_d;J_dM_d\rangle|^2}{(E-E_d)^2+\Gamma_d^2/4}\rho_f.\end{aligned}$$

This formula makes use of the isolated resonance approximation, in which interference effects between the intermediate states are neglected. The first matrix element describes the resonant capture of the free electron, where the operator $V_{capt.}$ is the sum of the Coulomb- and Breit-interaction operators. The second matrix element describes the radiative transition. The differential cross section can be expressed by means of the total cross section:

$$\frac{d\sigma^{DR}_{i\to d\to f}}{d\Omega_k} = \frac{\sigma^{DR}_{i\to d\to f}}{4\pi}\left(1+\beta P_2(\cos\theta)\right),$$

where θ denotes the angle of emission of the photon with respect to the direction of the incoming electron. The anisotropy parameter β depends on the matrix elements for resonant capture and on the total angular momenta of the intermediate and final states.

In order to obtain the cross section for RTE in the impulse approximation, the cross section for DR is convoluted with the probability density of the target electron in momentum space:

$$\frac{d^2\sigma_{RTE}}{d\Omega d\omega} = \int d^3q'\frac{d\sigma_{DR}(\mathbf{q})}{d\Omega}|\phi_i(\mathbf{q}')|^2\delta(\omega+E_f-e_i-E_i).$$

Here, $\phi_i(\mathbf{q}')$ denotes the Fourier transform of the wave function of the target electron in the target frame. The δ-function ensures the conservation of energy.

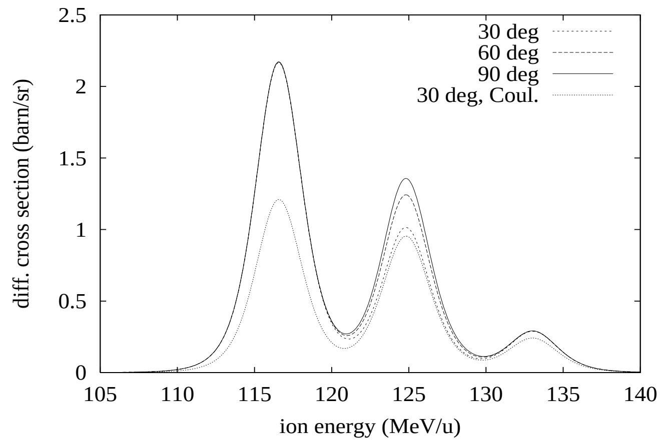

Figure 1: Differential cross sections for KLL-RTE in U^{91+} in the projectile frame at the angles $\theta = 30°$, $60°$ and $90°$.

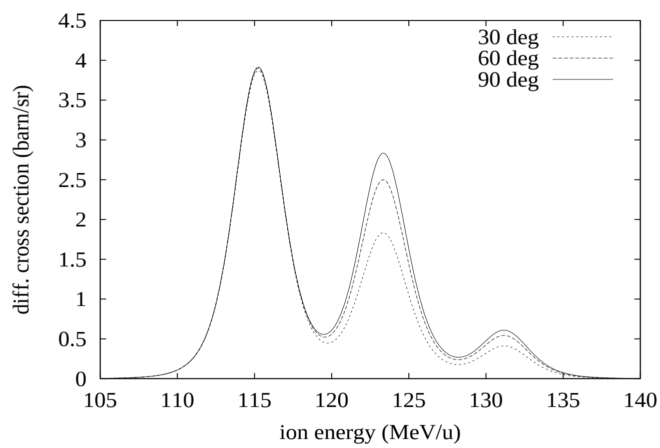

Figure 2: Differential cross sections for KLL-RTE in U^{90+} at the same angles.

Fig. 1 shows differential cross sections in the projectile system at different angles for U^{91+}-ions scattered on hydrogen atoms. The radiation has a strong angular dependence for energies in the range of the $KL_{1/2}L_{3/2}$ resonance group, while it is nearly isotropic for the other two resonance groups $KL_{1/2}L_{1/2}$ and $KL_{3/2}L_{3/2}$. The lowest curve was obtained by neglecting the effects of the Breit interaction.

The case of U^{90+}-ions is shown in Fig. 2. The cross section is anisotropic in the $KL_{1/2}L_{3/2}$ and $KL_{3/2}L_{3/2}$ groups. Also the cross sections are larger than the ones for the H-like projectile ions.

References

[1] X. Ma et al., this report (2001)
[2] T. Kandler et al., *Phys. Lett.* A **204** 274 (1995)
[3] M. Gail et al., *J. Phys.* B **31** 4645 (1998)