Two–photon angular correlations in the electron capture of high–Z ions

Andrey Surzhykov[1], Stephan Fritzsche[1] and Thomas Stöhlker [2,3]

[1]Fachbereich Physik, Universität Kassel, D–34132 Kassel; [2] GSI, D–62491 Darmstadt; [3] IKF, University of Frankfurt

During recent years, a large number of experiments have been carried out at the GSI storage ring in order to study the radiative recombination (RR) of free (or quasi–free) electrons into the bound states of highly charged ions. So far, most of the measurements concerned the electron capture into the K–shell of *bare* projectile ions for which the total and angle–differential cross sections have been studied in detail by Stöhlker and co–workers [1]. In later years, several experiments were focused also on the radiative recombination into the *excited* states of the projectile ions, and their subsequent photon decay, since the angular distribution of the characteristic radiation may provide useful information about the population of the ionic sublevels following an electron capture. From the measurement of the anisotropic emission of the *Lyman*–α_1 ($2p_{3/2} \to 1s_{1/2}$) radiation, for instance, a significant alignment of the $2p_{3/2}$ state of hydrogen–like uranium was deduced recently [2].

So far, however, the angular distributions of the *recombination* and the subsequent *decay* photons have been studied separately. More information about the dynamics of the capture process as well as the structure of the highly–charged hydrogen–like ions can be obtained, if both photons are observed in a (e, 2γ) coincidence experiment. Owing to recent advances in x–ray detector techniques, such coincidence measurements are likely to be carried out at the GSI storage ring in the future.

For the theoretical treatment of such particle–particle correlation phenomena, the most natural framework is given by the density matrix theory [3]. Within this theory, the (e, 2γ) radiative recombination is described as a two–step process where, in the first step, a free electron is captured into an excited ion state of the projectile ion under the simultaneous emission of the *"recombination"* photon γ_{RR}. This electron capture usually leads to the *non–statistical* population of the magnetic sublevels $|n_b j_b \mu_b>$ of the residual ion. Within the framework of the density matrix theory, the population of the ionic substates is described in terms of so–called "reduced statistical tensors" $\mathcal{A}_{kq}$. In general, these tensors depend on the *collisional* parameters such as the projectile ion energy T_p and its nuclear charge Z as well as on the angle θ_{RR} with respect to the ion beam, under which the "recombination" photon is emitted.

The statistical tensors $\mathcal{A}_{kq}(\theta_{RR})$ of the excited ion state directly affect also to the properties of the subsequent *"decay"* photons, which are emitted in the second step of the (e, 2γ) process. If we consider, for instance, the electron capture into the $2p_{3/2}$ state of bare ion, the angular distribution of the *Lyman*–α_1 ($2p_{3/2} \to 1s_{1/2}$) radiation (in the reaction plane) is defined by the reduced statistical tensors of the second rank as:

$$W(\theta_{Ly}, \theta_{RR}) \propto 1 + \frac{1}{2}\sqrt{\frac{4\pi}{5}} \sum_{q=-2}^{q=2} Y_{kq}(\theta_{Ly}, 0) \times \mathcal{A}_{2q}(\theta_{RR})\, f(E1, M2), \qquad (1)$$

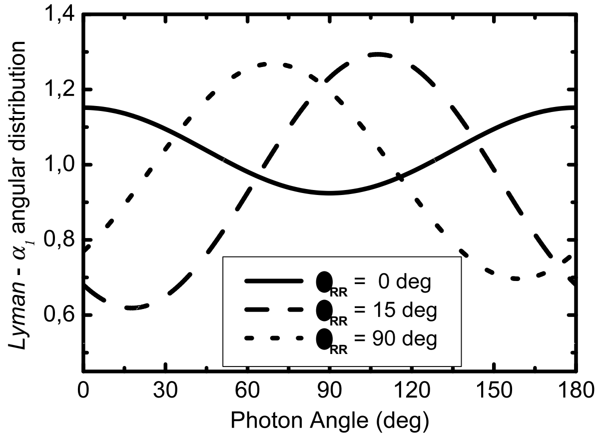

Figure 1: Angular distribution of the *Lyman*–α_1 radiation following the radiative recombination of a free electron into the $2p_{3/2}$ state of the bare U^{92+} ion with energy $T_p = 220$ MeV/u. Distributions are shown in the projectile frame.

where $f(E1, M2)$ is called the *structure function* [3] which describes the interference between the electric dipole (E1) and the magnetic quadrupole (M2) transition amplitudes.

The angular distribution $W(\theta_{Ly}, \theta_{RR})$ (1) represents the photon–photon angular correlation function for the electron capture into $2p_{3/2}$ state and the following *Lyman*–α_1 decay. This function depends not only on the emission angle of the "decay" photon but also on the angle θ_{RR} under which the "recombination" photon is detected. Figure 1 displays, for instance, the *Lyman*–α_1 angular distributions for three different angles $\theta_{RR} = 0°$, $15°$ and $90°$ of the "recombination" photon. As seen from this Figure, the *Lyman*–α_1 distribution is symmetric around the angle $\theta_{Ly} = 90°$ for a forward emission of the "recombination" photon ($\theta_{RR} = 0°$) as it is expected from the *axial* symmetry of the overall system. In contrast, the emission of the "recombination" photon under any other angle ($\theta_{RR} \neq 0°$ and $180°$) breaks down the axial symmetry of the system and gives rise to an asymmetric angular distribution of the *Lyman*–α_1 photons in coincidence measurements.

In the future, therefore, we expect the photon–photon angular correlation measurements to provide a tool for determining the polarization of either the electron target or the ion beam. Moreover, such coincidence studies may help distinguish between different population mechanisms of the excited states, following either the direct electron capture or cascade feeding from the upper levels. A more detailed analysis of such polarization and correlation effects is currently under the way.

References

[1] Th. Stöhlker, Physica Scripta **T80** (1999) 165.

[2] Th. Stöhlker *et al.*, Phys. Rev. Lett. **79** (1997) 3270.

[3] A. Surzhykov *et al.*, J. Phys. B **35** (2002) 3713.