Proposed determination of small level splittings in highly charged ions

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Highly charged ions (HCI) are known as a unique tool for exploring the interaction of strong electromagnetic fields with matter. In particular the x-ray emission from these ions has been investigated for many years and helped reveal many details about the structure and dynamics of HCI [1]. Moreover, recent studies on the angular distribution and linear polarization of these x-rays provided not only insight into the electron-electron and electron-photon interactions but also showed a rather strong influence of the hyperfine interaction upon the angular x-ray emission of HCI, even if the fine and hyperfine structure of these lines cannot be resolved in detail [2].

Until the present, however, almost all experimental and theoretical investigations on the angular distribution of x-rays have dealt with the photon emission from well-isolated fine-structure levels. In contrast, little attention was paid to cascade emissions that proceed via two (or more) overlapping intermediate resonances. For such cascades, we have therefore explored, by using the density matrix theory, both the photon-photon correlation function as well as the angular distribution of the second photon (if the first photon remains unobserved). General expressions were derived for these distributions, independent of the particular shell structure of the HCI [3]. For the sake of simplicity, let us consider the two-step cascade

$$\begin{aligned} & 1s2p^2 \;\; J_i = 1/2, 3/2 \\ & \longrightarrow \;\; \gamma_1 \, + \left\{ \begin{array}{l} 1s2s2p \;\; J = 1/2 \\ 1s2s2p \;\; J' = 3/2 \end{array} \right\} \\ & \longrightarrow \;\; \gamma_1 \, + \, \gamma_2 \, + \, 1s^2 2s \;\; J_f = 1/2 \end{aligned} \qquad (1)$$

of lithium-like ions. These ions have a relatively simple level structure and are known to exhibit a level crossing of the two $1s2s2p \;\; J = 1/2, 3/2$ intermediate resonances between $74 \leq Z \leq 79$. For this decay cascade, indeed, a quite remarkable effect of the level splitting and the alignment of the initial $1s2p^2 \;\; J_i = 3/2$ resonance is found for the angular distribution of the emitted x-ray photons. For lithium-like W^{71+} ions, for example, Fig. 1 displays the angular distribution of the second-step photon emission for an initially aligned $1s2p^2 \;\; J_i = 3/2$ resonance with (alignment parameter) $\mathcal{A}_2 = -1.0$ and for four different splittings of the intermediate $J = 1/2$ and $3/2$ levels (all in a.u.).

When compared with the photon emission of isolated levels, the x-ray emission via overlapping resonances is affected also by spin-spin and spin-orbit interactions that give rise to a depolarization (in time) of these intermediate levels. This effect of partially overlapping resonances upon the emission of photons and electrons has been termed *lifetime-induced depolarization* in the literature. If no further details are known about the exact time interval between the subsequent emission processes in some cascade, this depolarization can be characterized by means of so-called depolarization factors that just depend on the energy splitting and the natural width of the intermediate resonances.

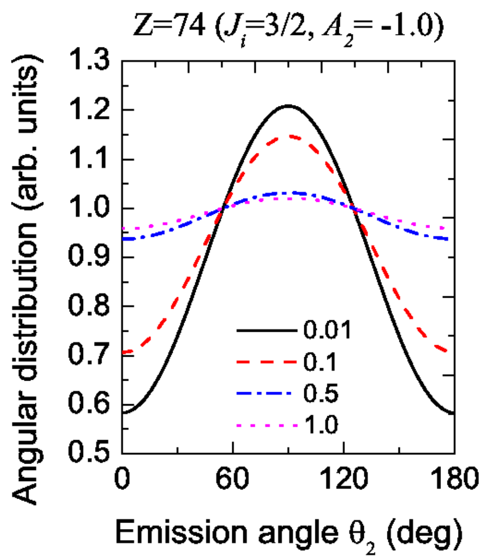

Figure 1: Angular distribution of the second-step photon emission for the cascade (1). See text for further discussions.

Owing to the strong dependence of the photon-photon correlation and angular distribution functions upon the energy splitting of the intermediate levels, we conclude that accurate measurements of the angular x-ray emission may serve also as a tool for determining small level splittings in highly charged ions [3]. Such measurements of the photon angular distributions will be feasible with present-day x-ray detectors and could be carried out at both, heavy-ion storage rings and electron beam ion trap facilities.

References

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DOI:10.15120/GR-2015-1-APPA-MML-AP-16