The Lyman–α_1 Decay in Hydrogen-like Ions: Interference between the E1 and M2 Transition Amplitudes

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We report on an interference between the **E1** and **M2** transition amplitudes in the decay of the $2p_{3/2}$ level in hydrogen–like heavy ions which significantly alters the photon angular distribution of the *Lyman*–α_1 transition ($2p_{3/2} \rightarrow 1s_{1/2}$). In the past, the angular distribution of this decay was subject of intense experimental and theoretical studies in order to elucidate the magnetic substate population of Radiative Electron Capture (REC) in relativistic collisions of bare uranium with low-Z target atoms [1, 2]. If the magnetic sublevels with different absolute magnetic quantum numbers μ are populated non-statistically, alignment occurs leading to an anisotrope emission pattern. For the particular case of the $2p_{3/2}$ state this angular distribution is given by [1]

$$W(\theta) \propto 1 + \beta_{20}(1 - \frac{3}{2}\sin^2\theta) \tag{1}$$

where θ is the angle between the direction of the excitation photon and the beam direction (emitter frame) while β_{20} denotes the anisotropy coefficient. In the case of the $2p_{3/2}$ level, the anisotropy coefficient can be expressed as:

$$\beta_{20} \;\; = \tfrac{1}{2} \cdot \;\; \frac{\sigma(\frac{3}{2}, \pm\frac{3}{2}) \, - \, \sigma(\frac{3}{2}, \pm\frac{1}{2})}{\sigma(\frac{3}{2}, \pm\frac{3}{2}) \, + \, \sigma(\frac{3}{2}, \pm\frac{1}{2})}, \tag{2}$$

Here $\sigma(3/2, \mu_n)$ describes the population of substate μ_n of the $2p_{3/2}$ level. The well known expression (2) takes into account only the dominant electric dipole (**E1**) term whereas the weaker magnetic quadrupole component (**M2**) is neglected. Based on expression (2), the theoretical and observed angular distributions were compared in detail and a remarkable variance was found [1, 2]. This deviation was surprising also in the sense that the REC is otherwise one of the best studied processes for high-Z, hydrogen-like ions for which an excellent agreement between theory and experiment is typically found. By using the density matrix theory one can consider the magnetic (**M2**) decay branch in a coherent way. As a result, the alignment coefficient parameter β_{20} must now be replaced by the product $\beta_{20} \cdot f(E1, M2)$ where $f(E1, M2)$ is a *structure* function which takes into account the interference effect. Note, for H-like uranium the structure parameter $f(E1, M2)$ reaches a value of as large as 1.28 [3]. In Fig. 1 we compare the experimental results for H-like uranium (solid points) with the corresponding theoretical findings (full line) and the results obtained assuming $f(E1, M2) = 1$ (dashed line), i.e. neglecting the interference term. From the figure it is evident that the former departure of the theoretical results from the experimental values is removed then taking the interference term into account. This proves the importance of the interference between the **E1** and **M2** decay branches for the decay of $2p_{3/2}$ state. Also, we have to add that one may expect similar sizeable corrections for any other atomic transitions in the high-Z regime where beside the leading **E1** term, higher multipole contributions are small but allowed. Here, e.g. doubly excited states in He-like ions such as produced by KLL-dielectronic recombination must be mentioned [4, 5]. More general, the study of decay rates and transition matrix elements of atomic transitions are of great importance to test and advance our basic knowledge about the physics of strong Coulomb fields as they are present at high-Z. However, at high-Z, most of these transitions exhibit such fast decay rates that lifetime measurements are excluded. Because of the sensitivity of the effective alignment parameter on the reduced matrix elements of the multipole transitions involved, the latter can be addressed by measuring precisely the associated photon angular distributions. It represents therefore an experimental tool to study the decay properties of atomic states in the realm of high-Z ions.

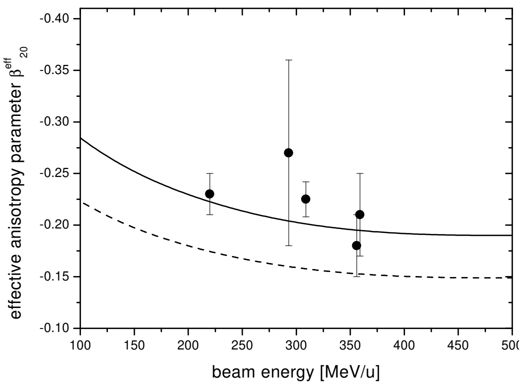

Figure 1: The experimentally determined effective anisotropy parameters $\beta_{20}^{\mathrm{eff}}$ (solid points) for the *Lyman*–α_1 radiation of U^{91+} produced in $U^{92+} \rightarrow N_2$ collisions as a function of collision energy [2]. The dashed line represents the theoretical predictions for $f(E1, M2) \equiv 1$, i.e. when the interference term is neglected. The solid line shows the corresponding theoretical result which considers the interference term $f(E1, M2)$, i.e. $\beta_{20} \cdot f(E1, M2)$.

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