Accessing the hyperfine splitting in highly charged helium-like ions via angle-resolved x-ray spectroscopic analysis

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Synopsis A new scheme is presented for determining the hyperfine splitting of highly charged ions via angle-resolved spectroscopic analysis. In particular, we propose two measurements on the angular distribution and linear polarization of the emission line $1s2p\ ^3P_1, F = I-1, I, I+1 \to 1s^2\ ^1S_0, F_f = I$ of He-like isotopic ions, following the stimulated decay of the $1s2s\ ^1S_0, F_i = I$ level. We find that the angular and polarization behavior of the emitted photons strongly depends on the splitting of the overlapping hyperfine $1s2p\ ^3P_1, F$ resonances, which could be a promising "signature" for the hyperfine splitting determination.

Hyperfine splitting in highly charged high-Z ions helps to perform accurate tests of QED in strong electromagnetic fields as generated by heavy nuclei. H-like ions as the simplest atomic system have received much attention for such kind of studies. For instance, the first successful measurement was performed for the $1s$ hyperfine splitting of H-like $^{209}_{83}$Bi^{82+} ions [1].

Helium-like ions are still simple enough to be expected to serve for such QED tests. To the best of our knowledge, however, there have been no such kind of experimental studies up to now, although some theoretical work has been done. When compared to H- or Li-like ions, the ground state of He-like ions does not split into hyperfine levels. As for the excited levels like $1s2p\ ^{1,3}P_1, F$, their linewidth is comparable to or even larger than their hyperfine splitting, which are hardly resolved due to their mutual overlap.

For this reason, we here propose a new scheme to measure the hyperfine splitting in He-like ions by analyzing the angular distribution and linear polarization of emitted fluorescence photons. More specifically, we consider the two-step radiative decay

$$\begin{aligned} 1s2s\ ^1S_0, F_i = I + \gamma_1(\hbar\omega) \\ \longrightarrow \quad 1s2p\ ^3P_1, F = I-1, I, I+1 \\ \longrightarrow \quad 1s^2\ ^1S_0, F_f = I + \gamma_2 \end{aligned} \qquad (1)$$

of He-like ions in order to resolve the hyperfine splitting of the intermediate levels. In this scheme, the initial level $1s2s\ ^1S_0, F_i = I$ can be populated via the K-shell ionization of Li-like ions at ion storage rings [2], or alternatively, via the prompt $2s2p\ ^1P_1, F = I-1, I, I+1 \to 1s2s\ ^1S_0, F = I$ decay following the resonant electron capture of initially H-like ions into the $2s2p\ ^1P_1$ level [3]. The first-step decay may further be stimulated by a laser that has proper intensity and adjustable γ_1 photon energy in order to compete with dominant $2E1$ decay of the initial $1s2s\ ^1S_0, F_i = I$ level. Finally, the fluorescence γ_2 photons as emitted in the subsequent spontaneous decay are observed.

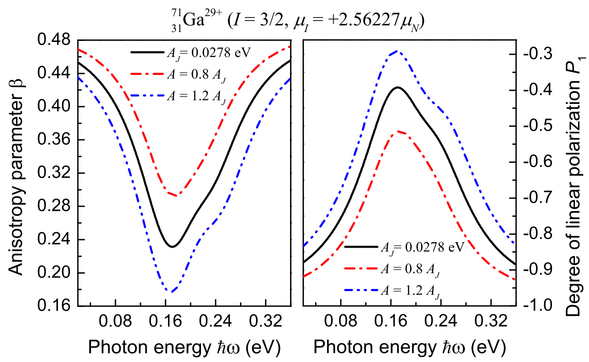

Figure 1. Anisotropy parameter β and linear polarization P_1 of the γ_2 photons for $^{71}_{31}$Ga^{29+} ions as functions of photon energy of the stimulating laser. Results are given for the calculated hyperfine constant $A_J = 0.0278$ eV as well as for two assumed values $0.8A_J$ and $1.2A_J$.

Figure 1 shows the calculated γ_2 angular distribution and linear polarization for $^{71}_{31}$Ga^{29+} ions. As seen clearly, these angular and polarization properties depend strongly on the hyperfine structure values. This could be used as a "signature" for determining the associated hyperfine splitting. We therefore suggest that accurate x-ray measurements may indeed serve as a promising tool to measure the hyperfine splitting in highly charged He-like ions.

References

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