Photon Polarization in Radiative Recombination of Bare High–Z Ions

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The radiative recombination (RR) and radiative electron capture are two well–established processes from the study of electron–ion and atom–ion collisions. In these processes, a free or quasi–free electron is captured into a bound state of the ion, accompanied by the simultaneous emission of a photon. For bare high–Z ions, for example, the radiative recombination has been explored in detail by Stöhlker and co–workers [1] at the GSI storage ring during recent years. So far, however, most experiments were focused on measuring the total and angle–differential recombination cross sections which are typically found in good agreement with theoretical predictions, based on Dirac's theory [2]. Much less attention, in contrast, has been paid previously to the polarization of the emitted radiation, mainly because of the lack of efficient polarization detectors for hard x–rays. Only in the light of recent improvements in detector techniques, the observation of the photon polarization has become more likely within the next few years.

To predict the polarization of the photons which are emitted in the recombination of free electrons into a bound state of the bare ions, theoretical studies have been carried out in the framework of the *density matrix approach* [3]. In the past, this approach has been utilized successfully in a large number of case studies on the *polarization* as well as *correlation* phenomena in many areas of the nuclear and atomic physics. In fact, this formalism provides us with a tool of great elegance in the theoretical analysis of collision and decay processes.

In the framework of the density matrix theory, the photon polarization is directly related to three *Stokes parameters* (P_i, i=1..3). While the first two parameters are usually used for the characterization of the linear polarization $P_L = \sqrt{P_1^2 + P_2^2}$, the third Stokes parameter describes the circular polarization of the photons $P_C = P_3$ [4]. As for the computation of cross sections, these parameters are closely connected to the matrix element

$$M^{RR}_{b,\,\mathbf{p}}(m_s, \lambda, \mu_b) = \int d^3r \psi^{\dagger}_{j_b \mu_b}(\mathbf{r})\, \alpha\, \hat{\mathbf{u}}^*_{\lambda}\, e^{-i\mathbf{k}\mathbf{r}}\, \psi_{\mathbf{p},m_s}(\mathbf{r}) \quad (1)$$

which refers to the radiative transition of a free electron with asymptotic momentum $\mathbf{p}$ and spin projection m_s in the bound–state of the bare ion. In recent years, this *relativistic* form of the transition matrix has been widely used for studying the radiative recombination of high–Z ions at intermediate and high collision energies [2]. For a capture into bare ions, $\psi_{j_b\mu_b}(\mathbf{r})$ and $\psi_{\mathbf{p},m_s}(\mathbf{r})$ are the known solutions of Dirac's Hamiltonian for a bound or continuum electron, respectively. Moreover, the unit vector $\hat{u}_\lambda$ denotes the polarization of the photons. For the numerical calculations of the matrix element (1) and, hence for, the photon polarization, we used the computer code DIRAC [5].

Calculations for different polarization parameters of the emitted photons have been carried out as function of the projectile ion energy [4]. For instance, Figure 1 shows the degree of linear polarization P_L of the photons which are emitted due the capture of a free electron into the K shell of Bi^{83+} projectiles. Since, in experiment, the radiative recombination of ions is usually studied by collisions of bare, high–Z projectiles with (low–Z) target atoms, here we present the Stokes parameter for angles measured in the *laboratory system* (the rest frame of the target atoms) with respect to the *beam direction.* As seen from Figure 1, a very high degree of polarization arises for a wide range of angles.The density matrix theory provides a consistent framework to investigate not only the *polarization* properties of the photons and residual ions but also the total as well as differential cross sections of the electron capture processes [4]. Moreover, this theory can be easily extended to study the two– (or multi–) step radiative recombination. In such processes, an electron is captured into any of the excited ion states which will further decay by emission of one or several subsequent photons. This subsequent photon decay in the high–Z hydrogen–like ions can provide new information about the electron structure of atoms and ions in strong Coulomb fields [5].

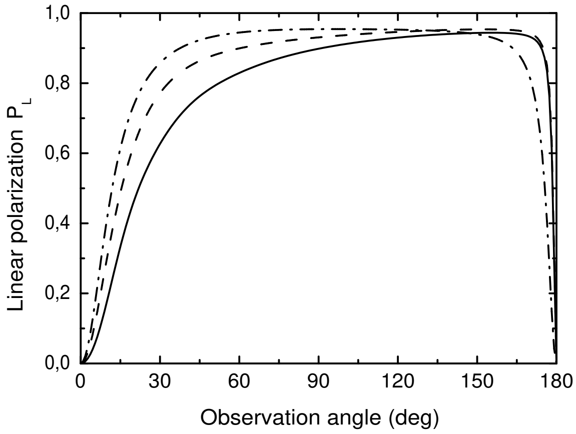

Figure 1: Degree of linear polarization of the emitted photon as a function of the *laboratory* photon angle for the K–RR of Bi^{83+} projectiles. The linear polarization is shown for three projectile energies: T_p = 10 MeV/u (– - –), T_p = 100 MeV/u (– –), and T_p = 220 MeV/u (—).

References

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