Quantum correlations in the radiative recombination into excited state of highly charged heavy ions

A. V. Maiorova*,†[1], S. Tashenov◇, A. Surzhykov‡, V. M. Shabaev†, T. Stöhlker‡,⋆

*Center for Advanced Studies, St.Petersburg State Polytechnical University, Polytekhnicheskaya 29, St.Petersburg 195251, Russia

† Department of Physics, St.Petersburg State University, Ulianovskaya 1, Petrodvorets, 198504 St.Petersburg, Russia

◇ Physikalisches Institut, Universität Heidelberg, D-69120 Heidelberg, Germany

‡ Helmholtz-Institut Jena, D-07743 Jena, Germany

⋆ GSI Helmholtzzentrum für Schwerionenforschung GmbH, D-64291 Darmstadt , Germany

Synopsis We consider the radiative recombination of a free electron into the excited $2p_{3/2}$ state of heavy H-like ion with the subsequent decay into the ground $1s_{1/2}$ state. Quantum correlations between two photons emitted in the process are studied.

Radiative recombination (RR) is one of the basic processes that occurs in laboratory plasma, in collisions of heavy ions with electrons at ion storage rings and EBIT. During the last decades RR of highly charged heavy ions remains the subject of intense theoretical and experimental research (see Ref. [1] and references therein). Radiative recombination is a time-reversed photoionization, hence it allows to study this fundamental electron-photon interaction in large-energy and strong-field regime, which is not accessible in the direct channel. Moreover, the RR is very sensitive to the spin, relativistic and QED effects in the structure and dynamics of heavy atomic systems.

In the present work we investigate the radiative recombination of the relativistic electron with bare heavy ion into the $2p_{3/2}$ excited state of H-like ion and its subsequent Lyman-α_1 ($2p_{3/2} \to 1s_{1/2}$) decay. We consider the scenario where RR photon and subsequently emitted characteristic photon are detected in coincidence. In this case the axial symmetry of the RR-populated $2p_{3/2}$ state is removed and the magnetic sublevels of the highly charged ion are populated coherently [2]. We have employed the density matrix approach and relativistic Dirac's theory for description of such coherence between the magnetic substates [3].

We also apply our results to test Clauser-Horne-Shimony-Holt's (CHSH) inequality

$$|\Delta(\mathbf{a}, \mathbf{a}', \mathbf{b}, \mathbf{b}')| \leq 2, \tag{1}$$

which is one of a family of Bell inequalities. Here

$$\Delta(\mathbf{a}, \mathbf{a}', \mathbf{b}, \mathbf{b}') = E(\mathbf{a}, \mathbf{b}) - E(\mathbf{a}, \mathbf{b}') + E(\mathbf{a}', \mathbf{b}) + E(\mathbf{a}', \mathbf{b}'), \tag{2}$$

where $\mathbf{a}$, $\mathbf{a}'$ are the detector settings for the first photon and $\mathbf{b}$, $\mathbf{b}'$ for the second one, and $E(\mathbf{a}, \mathbf{b})$ is the correlation function for the photon pair.

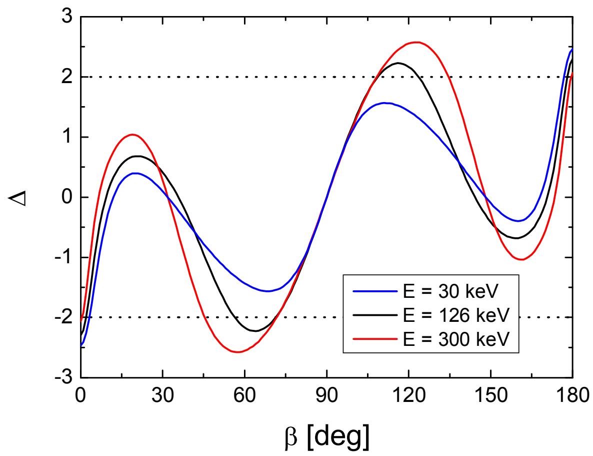

Figure 1. Test of CHSH inequality (2). β is angle between $\mathbf{a}$ and $\mathbf{b}$, $\mathbf{b}$ and $\mathbf{a}'$, and $\mathbf{a}'$ and $\mathbf{b}'$ [4].

This work was supported by SPbSU (Grants No. 11.38.269.2014 and No. 11.38.237.2015), by the Dynasty Foundation and by the grant of the President of the Russian Federation (Grant No. MK-1676.2014.2).

References

[1] J. Eichler and Th. Stöhlkler, Phys. Rep. **439**, 1 (2007).

[2] N. Andersen, J. Gallagher, and I.V. Hertel, Phys. Rep. **165**, 1 (1988).

[3] S. Tashenov *et al*, Phys. Rev. Lett. **113**, 113001 (2014).

[4] K. Blum, *Density Matrix Theory and Applications* (Springer, New York, 2012).

[1]E-mail: maiorova@pcqnt1.phys.spbu.ru