The Standard Model in Strong Fields: Electroweak Radiative Corrections for Highly Charged Ions

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Electroweak radiative corrections to the matrix element $< ns_{1/2}|\hat{H}_{\rm PNC}|n'p_{1/2} >$ are calculated for highly charged hydrogenlike ions. The operator $\hat{H}_{\rm PNC}$ represents the parity non-conserving relativistic effective atomic Hamiltonian at the tree level. The deviation of these calculations from the calculations valid for the neutral atoms demonstrates the effect of the strong field. We consider only the nuclear spin-independent part of $\hat{H}_{\rm PNC}$:

$$\hat{H}_{\rm PNC} = A_{\rm PNC}\, \gamma_5 \rho_N(r) \,, \tag{1}$$

where γ_5 is the Dirac matrix and $\rho_N(r)$ is the nuclear density.

$$A_{\rm PNC} = \frac{\pi\alpha}{4M_Z^2} P_W \,, \tag{2}$$

where α is the fine structure constant and M_Z is the mass of Z-boson. At the tree level we have

$$P_W = \frac{-N + Z(1-4s^2)}{s^2(1-s^2)} \tag{3}$$

where $s^2 = \sin^2\theta_W$, θ_W is the Weinberg angle, N is the number of neutrons in the nucleus, Z is the numbers of protons. According to [1], all the electroweak radiative corrections can be divided in two classes. The first class, called "oblique" corrections, can be incorporated into the running coupling constants: $(\alpha^*(q^2=0)$, $s^*(q^2=0)$ and $M_Z^{*2}(q^2=0)$.), dependent on q^2, where q^2 is the momentum tranfer. The remaining corrections are called "specific" corrections.[1]

The remarkable feature of the formula (2) is that for all heavy elements of experimental interest P_W is very close to $-\frac{16}{3}N$. [1]. Therefore it is convenient to introduce the quantity

$$\tilde{P}_W = -\frac{3}{16N} P_W \,. \tag{4}$$

Then the "oblique" radiative corrections can be included in $\tilde{P}_W$.

PNC experiments in atomic physics provide an important possibility to deduce informations on the Standard Model independent of high-energy physics experiments and for the search of all types of the "new physics" beyond the minimal Standard Model, e.g., for the existence of a second Z-boson etc.. Atomic PNC experiments are usually performed on heavy neutral atoms (Cs, Bi, Tl), however the electrons in these atoms are loosely bound valence electrons and the corresponding momentum transfer $q^2 \ll m_e^2$ .. The situation is different in highly charged ions (HCI), where $q^2 \approx m_e^2$. In the strong field the electrons are described in the QED Furry picture [2], that means the electrons are considered in the external field from the beginning.

To analyse the PNC radiative corrections in HCI, we note, that the dominant field dependent corrections are the wave-function electron loop corrections and the electromagnetic Z-boson coupling renormalization corrections. An order of magnitude estimate for the relative compared to tree level effects correction gives:

$$\delta_P^{\mathrm{loop-w.f.}} \approx \alpha(\alpha Z)^2 \, . \tag{5}$$

By the exact numerical evaluations for Z=92 we obtain the value of $\delta_P^{\mathrm{loop-w.f.}} = 0.01225$. This is comparable with the main "oblique" radiative correction that represent the effect of the running M_Z^2 constant: $\delta_P^M \equiv 0.0880$ [1].

Acknowledgments The authors are grateful to M.G.Kozlov for fruitful discussions. The work of I.B. and L.L. was supported by the Russian Foundation for Basic Research, grant $N \stackrel{0}{=} 99-02-18526$, the work of I.B. also by the Administration of St.Petersburg, grant $N \stackrel{0}{=} M-97-2.2d-974$. G.S. and G.P. acknowledges support by the BMBF, the DFG, and by GSI (Darmstadt).

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