Parity–violating transitions in beryllium–like ions*

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Parity–violation (PV) phenomena in highly–charged ions currently attract much attention (see e.g. [1, 2]). In particular, many studies are focused on the mixing between opposite–parity atomic levels caused by the weak electron–nucleus interaction. A number of proposals have been made to detect such a mixing and, hence, to explore the basic parameters of the electroweak theory. Most of theses proposals have dealt up to now with the near–degenerate $1s2s$ and $1s2p_{1/2}$ states of helium–like *heavy* ions for which the PV effects are significantly enhanced. In the high–Z domain, however, the lifetimes of such singly–excited states are shorter than $\tau \sim 10^{-10}$ seconds which makes the observation of the parity–violating phenomena in two–electron systems rather challenging. During the recent years, therefore, particular interest has been given to other few–electron species whose *long–lived* levels might be mixed by the weak interaction.

Owing to their shell structure, beryllium–like heavy ions may provide an alternative and promising tool for studying atomic PV phenomena. For the case of *zero* nuclear spin, the first excited state of these ions, $1s^2\,2s\,2p\;^3P_0$, can decay to the $1s^2\,2s^2\;^1S_0$ ground level solely by the strongly suppressed two–photon $E1M1$ emission and, hence, has a lifetime of the order of seconds. Moreover, the energy splitting between these two levels does not exceed 260 eV even for the heaviest ions, thus leading to a rather remarkable $^1S_0$–$^3P_0$ parity–violating mixing [3]. To observe such a mixing, we have recently proposed to utilize the source of the coherent extreme ultraviolet (EUV) radiation and to induce a single–photon transition between the metastable $1s^2\,2s\,2p\;^3P_0$ and short–lived $1s^2\,2s\,2p\;^3P_1$ levels [4]. Since the $^3P_0$ state has a small PV–admixture of the ground one, such an absorption can proceed not only via the allowed $M1$ but also the parity–violating $E1$ channel (see Fig. 1).

The interference between the $M1$ and PV–$E1$ excitation channels becomes "visible" if the $1s^2\,2s\,2p\;^3P_0 \rightarrow 1s^2\,2s\,2p\;^3P_1$ transition is induced by the circularly polarized light. In this case the photoexcitation cross section reads as [4]:

$$\sigma_\lambda = \sigma_{M1}\,(1+\lambda\epsilon)\;, \qquad (1)$$

where $\lambda = \pm 1$ for the right– and left–hand polarization, σ_{M1} describes the leading, parity–preserved $^3P_0 \rightarrow {}^3P_1$ magnetic dipole channel, and the so–called asymmetry coefficient ϵ is given by:

$$\epsilon = -2\,\eta_{PV}\,\frac{\langle 1s^2 2s2p\;^3P_1\,\|E1\|\,1s^2 2s^2\;^1S_0\rangle}{\langle 1s^2 2s2p\;^3P_1\,\|M1\|\,1s^2 2s2p\;^3P_0\rangle}\,. \qquad (2)$$

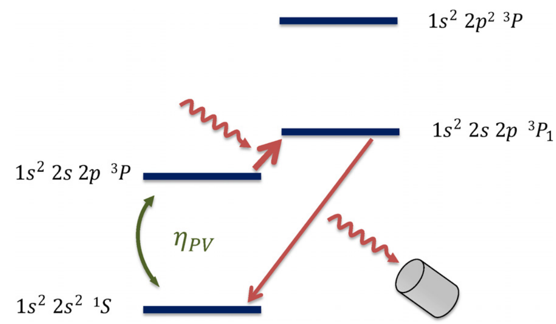

Figure 1: Proposed scheme for measuring the PV–mixing between the ground $1s^2\,2s^2\;^1S_0$ and the first excited $1s^2\,2s\,2p\;^3P_0$ states of beryllium–like heavy ions. For the case of U^{88+}, the energies $E_{^3P_0}$ and $E_{^3P_1}$ if defined relative to the ground state energy are 258.3 and 298.2 eV, correspondingly. From Ref. [4].

In this expression, $\langle ...\,\|E1, M1\|\,...\rangle$ are the reduced matrix elements for the $^1S_0 \rightarrow^3 P_1$ ($E1$) and $^3P_0 \rightarrow^3 P_1$ ($M1$) transitions, and the parameter η_{PV} describes the PV–mixing between the $^1S_0$ and $^3P_0$ states.

The asymmetry parameter ϵ is the physical observable in the proposed experiment. It can be determined by inducing the $1s^2\,2s\,2p\;^3P_0 \rightarrow 1s^2\,2s\,2p\;^3P_1$ transition separately with left– and right– circularly polarized light and by recording then the intensity difference of the x–rays from the decay of the $^3P_1$ state. Since these intensities are proportional to the photo–excitation cross sections (1), $I_\lambda(^3P_1 \rightarrow^1 S_0) \sim \sigma_\lambda$, we can find:

$$\epsilon = \frac{I_+ - I_-}{I_+ + I_-}\,. \qquad (3)$$

In order to provide an estimate of this asymmetry parameter, detailed calculations have been performed within the framework of the multi–configuration Dirac–Fock (MCDF) approach [4]. Based on these calculations, we argue that the most suitable candidate for the experimental realization of the proposed scheme is beryllium–like uranium U^{88+}. For this ion, the PV–mixing between the $1s^2\,2s\,2p\;^3P_0$ and $1s^2\,2s^2\;^1S_0$ states gives rise to $\eta_{PV} = -1.0\times10^{-8}$ and the asymmetry parameter $\epsilon = 3.1\times10^{-7}$.

References

[1] V. M. Shabaev *et al.*, Phys. Rev. A 81 (2010) 052102.
[2] A. Bondarevskaya *et al.*, Phys. Rep. 507 (2011) 1.
[3] M. Maul *et al.*, J. Phys. B: At. Mol. Phys. 31 (1998) 2725.
[4] A. Surzhykov *et al.*, Phys. Scr. (2013), accepted.

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