Parity-nonconservation effects on the radiative recombination of heavy hydrogenlike ions

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Based on the theoretical analysis of the radiative recombination of heavy hydrogen-like ions with unpolarized electrons, a scheme is proposed for observing atomic parity nonconservation (PNC). The scheme employs the sensitivity of the polarization properties of recombination photons on the PNC-induced mixing of opposite-parity ionic levels. For the electron capture into the $1s2p\,^3P_0$ state of helium-like ions, in particular, the PNC leads to a rotation of the photon linear polarization on the angle, directly proportional to the $1s2p\,^3P_0$–$1s2s\,^1S_0$ mixing parameter. Owing to the recent advances in the development of x-ray polarimeters, the observation of such a rotation angle and, hence, the corresponding parity mixing is likely to become feasible in the future.

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I. INTRODUCTION

The accurate and comprehensive test of the standard model of particles and interactions (SM) is one of the most challenging issues of modern physics. These studies play an important role in the examination of the electroweak segment of the SM that unifies the electromagnetic and weak interactions. Besides high-energy experiments at CERN and linear accelerators worldwide, precision electroweak measurements in atomic physics currently attract much attention since they allow the exploration of the low-energy regime, sensitive to a different combination of the neutral-current electron-quark coupling constants [1,2]. Usually these measurements aim to explore a *mixing* between opposite-parity atomic levels which is caused by the weak interaction. Observations of such parity-nonconservation (PNC) effects have been reported for various neutral atoms [3–5] and led to a high-precision determination of the Weinberg angle θ_W and even nuclear parity-violation parameters. This determination became possible due not only to recent experimental advances, but also the accurate theoretical analysis of interelectronic correlations and quantum electrodynamical (QED) effects in atoms [6–8].

Apart from neutral atoms, other systems were discussed recently as alternative testbeds for the (low-energy) parity-violation studies. For example, a number of proposals have been made to explore PNC phenomena in diatomic molecules, molecular ions, or singly ionized atoms [9–11]. Owing to the developments in accelerator and storage ring facilities, moreover, the application of *highly charged, heavy ions* has become feasible nowadays. Since the works by Gorshkov and Labzowsky [12], the helium-like ions are considered as very promising candidates for the parity-violation investigations not only due to their (relatively) simple electronic structure, but also due to a significant enhancement of the PNC effects in comparison with neutral systems. Besides the large overlap of the electronic density with the nucleus, the (near) degeneracy of opposite-parity ionic levels gives rise to such an enhancement. A large number of proposals have been made, for example, to exploit the energy crossing between the $1s2p\,^3P_0$ (briefly denoted as $2\,^3P_0$) and $1s2s\,^1S_0$ ($2\,^1S_0$) states and to determine the PNC mixing between these two levels [13,14]. Most of these proposals, however, required an operation with spin-polarized ion beams and/or intense circularly polarized light in the ultraviolet or even x-ray domains. None of these requirements can be easily accomplished today in practice. The development of new approaches is needed, therefore, to exploit the potential of helium-like ions for atomic PNC studies.

One of the very promising probe processes, which may be efficiently used to measure the parity violation effects, is the radiative recombination (RR) of electrons with initially hydrogen-like (finally helium-like) ions. For this capture process, it was recently shown that the $2\,^1S_0$-RR differential cross section may be sensitive to the $2\,^3P_0$–$2\,^1S_0$ weak mixing if the recombination photons of a particular *linear* polarization are recorded by x-ray detectors [15]. This scenario avoids the complications related to the production of polarized heavy ion beams (and electron targets) and relies on actively developing x-ray polarization detection techniques [16–31]. However, its practical realization is hampered by the fact that the application of the available detectors as *polarization filters* that selectively register photons of a given polarization is still not well elaborated. In this work, we therefore propose an alternative approach for studying the PNC by means of the radiative recombination of hydrogen-like ions. We argue that the information on the parity mixing of ionic states and, hence, on the key parameters of the weak interaction can be obtained most naturally from the analysis of the preferred *orientation* of the linear polarization of the RR photons. Modern position-sensitive solid-state detectors allow a very efficient determination of such an orientation [24,26,31]. In these detectors, the polarization analysis is traced back to the angular distribution of the Compton- or Rayleigh-scattered (in the detector material) photons. The shape of this distribution is well known and reflects the polarization direction of the incident light. By a proper fit of the spatial distribution of scattered events to theoretical predictions, the tilt angle of the linear polarization can therefore be determined with a high accuracy. Yet an alternative and very promising route to polarization measurements relies on the multiple Bragg reflections at channel-cut crystals [32]. By employing these crystals, one can achieve the (linear polarization) angle resolution of a few mdeg [33].

In this paper, we show that the linear polarization of the photons, emitted in the capture of unpolarized electrons into the $2\,^3P_0$ helium-like state is tilted by a characteristic angle if, in addition to the electromagnetic electron-photon coupling, the weak electron-nucleus interaction is taken into account. For the gadolinium ion, where the PNC effects are strongly enhanced by the near degeneracy of the mixed $2\,^3P_0$ and $2\,^1S_0$ states, such a rotation angle may reach $\sim 0.02^\circ$, which is just one order of magnitude smaller than the estimated sensitivity of present-day available x-ray polarimeters. Owing to the rapid progress in detection techniques, we therefore expect that the observation of the PNC-induced rotation of RR linear polarization will become feasible in the future and may open a new route for studying the parity-nonconservation phenomena in the atomic physics domain.

II. THEORETICAL BACKGROUND

To understand how the PNC phenomena affect the linear polarization of the recombination photons, we must first agree about the proper description of such a polarization. In atomic theory, the so-called Stokes parameters P_1 and P_2 are frequently used to characterize the polarization properties of light. These parameters are related to the *probabilities* to emit photons with the polarization vector oriented at different angles χ with respect to the reaction plane; the plane which is spanned by the directions of the incident beam and emerged light. The first parameter $P_1 = (W_{0^\circ} - W_{90^\circ})/(W_{0^\circ} + W_{90^\circ})$ reflects the emission of the photons, polarized in parallel ($\chi = 0^\circ$) and perpendicular ($\chi = 90^\circ$) to the reaction plane, while P_2 is defined by a similar ratio but with $\chi = 45^\circ$ and 135°, respectively.

The use of the Stokes parameters is very convenient for the analysis of the outcome of polarization measurements since they can be directly translated into experimental *observables*

$$P_L = \sqrt{P_1^2 + P_2^2}\,, \tag{1}$$

$$\cos 2\chi_0 = P_1/P_L, \quad \sin 2\chi_0 = P_2/P_L\,. \tag{2}$$

Here, P_L and χ_0 are the degree and the tilt angle of the photon's linear polarization. For the x-ray domain, both of these quantities are easily accessible with the modern solid-state polarimeters [26,29,30].

The theoretical analysis of the Stokes parameters P_1 and P_2 can be traced back to the spin-density matrix of the emitted photons

$$\langle \boldsymbol{k}\lambda|\hat{\rho}_\gamma|\boldsymbol{k}\lambda'\rangle = \frac{1}{2}\begin{pmatrix} 1+P_3 & P_1 - i\,P_2 \\ P_1 + i\,P_2 & 1 - P_3 \end{pmatrix}, \tag{3}$$

where $\lambda = \pm 1$ is the helicity of the photon (i.e., the spin projection onto the direction of propagation) and $\boldsymbol{k}$ denotes its momentum. Moreover, P_3 is the degree of circular polarization which usually remains unobserved in the present-day investigations. The explicit form of the density matrix elements on the left-hand side of Eq. (3) depends on the particular process under consideration. For the radiative recombination of unpolarized electrons into a *well-defined* ionic state $|\alpha_f J_f\rangle$, whose magnetic sublevels are not observed in a particular study, the elements of the density matrix read as

$$\langle \boldsymbol{k}\lambda|\hat{\rho}_\gamma|\boldsymbol{k}\lambda'\rangle = \frac{1}{2(2J_i+1)}\sum_{M_f\,M_i\,m_s}\langle \boldsymbol{k}\lambda,\alpha_f J_f M_f|\hat{\mathcal{R}}|\boldsymbol{p}m_s,\alpha_i J_i M_i\rangle \times \langle \boldsymbol{k}\lambda',\alpha_f J_f M_f|\hat{\mathcal{R}}|\boldsymbol{p}m_s,\alpha_i J_i M_i\rangle^*\,. \tag{4}$$

In this expression, $\boldsymbol{p}$ and m_s are the asymptotic momentum and spin projection of the incident electron, $\hat{\mathcal{R}}$ is the radiative transition operator, and the state $|\alpha_i J_i\rangle$ of the initial ion is assumed to be unpolarized.

As seen from Eqs. (3) and (4), the computation of the photon spin-density matrix and the Stokes parameters requires knowledge on the matrix elements of the operator $\hat{\mathcal{R}}$ that describe the free-bound electron transition under a simultaneous emission of the recombination photon. In the present study the transition amplitudes have been evaluated within the framework of the frozen-core Dirac-Fock approximation. Such a method, which approximates the many-particle wave functions by Slater determinants constructed from single-electron solutions of the Dirac equation with the screening potential, seems to be justified especially for the description of the RR in the high-Z domain (see, e.g., Refs. [34,35]).

Until now, no special assumptions about the shell structure of the initial- and the final-state ion have been made in our theoretical analysis. Equation (4), therefore, represents the most general form of the photon spin-density matrix. In the following we will employ this matrix to investigate the linear polarization of the x rays emitted in the radiative recombination of electrons into $|\alpha_f J_f\rangle = |1s2p\ ^3P_0\rangle$ state of (finally) helium-like ions. Owing to the weak interaction between the nucleus and bound electrons, this state no

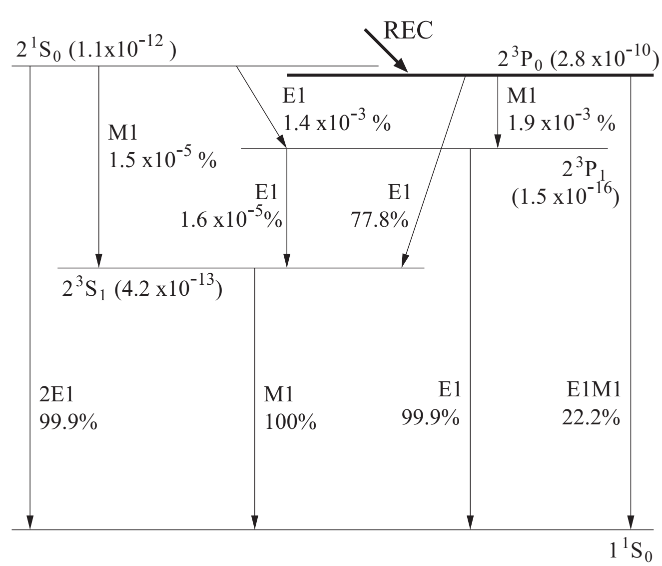

FIG. 1. The level scheme of the ground and first excited states of the helium-like gadolinium $^{152}Gd^{62+}$ [39]. Numbers in parentheses denote the lifetimes of the levels (in seconds).

longer has the pure parity $\mathcal{P} = -1$, but receives a small admixture of the closest-lying, opposite-parity $1s2s\,^1S_0$ level. One estimates such a mixing by introducing the effective (nuclear-spin-independent) weak-interaction Hamiltonian $\hat{H}_W = -(G_F/\sqrt{8})\,Q_W\,\rho_N(r)\,\gamma_5$, where G_F is the Fermi constant, $Q_W \approx -N + Z(1 - 4\sin^2\theta_W)$ is the weak charge of the nucleus, γ_5 is the Dirac matrix, and ρ_N denotes the effective nuclear weak-charge density normalized to unity [1]. The Hamiltonian $\hat{H}_W$ can be treated as a perturbation which leads to the modification of the $2\,^3P_0$ wave function

$$|2\,^3P_0\rangle \to |2\,^3P_0\rangle + i\xi|2\,^1S_0\rangle\,, \tag{5}$$

where the mixing coefficient reads as

$$\xi = -i\,\frac{\langle 2\,^1S_0|\hat{H}_W|2\,^3P_0\rangle}{E_{2\,^3P_0} - E_{2\,^1S_0} + i\Gamma/2}\,, \tag{6}$$

with $\Gamma \equiv \Gamma_{^1S_0}$ being the width of the $2\,^1S_0$ state. For heavy helium-like ions this width is in the meV region and about two orders of magnitude larger than $\Gamma_{2\,^3P_0}$, which was neglected in Eq. (6).

By inserting the modified state vector (5) into Eq. (4) we derive the density matrix of the photons emitted in the radiative recombination of unpolarized electrons into the $2\,^3P_0$ state, *mixed* with the $2\,^1S_0$ level. Such a density matrix can be subsequently utilized to express the Stokes parameters of RR x rays in terms of the (reduced) matrix elements of radiative transitions *and* the mixing parameter ξ. For the sake of brevity, we will not discuss here the details of the derivation and focus instead on the final results. That is, the parameters P_1 and P_2 were found to behave in rather different ways with respect to the parity-violation effects. While the P_1 remains unaffected by the parity mixing (6), the second Stokes parameter is directly proportional to ξ

$$P_1 = f_1(Z,T_p,\theta)\,, \quad P_2 = \xi\, f_2(Z,T_p,\theta)\,. \tag{7}$$

In these expressions, the functions $f_{1,2}$ merely depend on the collisional parameters such as projectile energy T_p and charge Z as well as the photon emission angle θ with regard to the ion beam.

As seen from Eq. (7), the linear polarization of the RR radiation would be characterized by a single parameter P_1 only if the mixing parameters ξ vanishes identically. Therefore, the purely electromagnetic electron-nucleus interaction results in the emission of the recombination photons that are polarized either within (if $P_1 > 0$) or perpendicular (if $P_1 < 0$) to the reaction plane; a well-known result as found in a variety of relativistic calculations done for collisions of unpolarized electrons [36–38]. In contrast, the account of the weak interaction gives rise to nonzero values of ξ and, thus, of the second Stokes parameter P_2, while it does not affect the first parameter P_1. A nonvanishing value of P_2 implies, however, an overall rotation of the linear polarization, independent of whether its orientation is within or perpendicular to the plane for $\xi = 0$. It is interesting to note that a similar rotation was predicted also for the capture of longitudinally *polarized* electrons [37]. This similarity can be understood from the fact that the weak interaction prefers left-handed particles and, hence, can be viewed to produce an effective "polarization" of the (initially unpolarized) electron beam which then leads to the overall rotation of the light polarization.

By making use of the Stokes parameters (7) in Eq. (2) and assuming a small level mixing due to parity-violating interactions $\xi \ll 1$, we can express the value of the polarization tilt angle a

$$\Delta\chi_{\rm PNC} \equiv \chi_0 - \chi_0^{\rm em} = \frac{\xi}{2}\,\mathcal{F}(Z,T_p,\theta) + O(\xi^3)\,. \tag{8}$$

Here, the notation $\mathcal{F} = f_2/f_1$ is introduced and $\chi_0^{\rm em}$ determines the preferential orientation of the linear polarization of RR photons obtained by neglecting the weak interaction. As mentioned above, this "purely electromagnetic" angle takes only two values $\chi_0^{\rm em} = 0^\circ$ and 90° if both incident electrons and hydrogen-like ions are initially unpolarized. As seen from Eq. (8), any nonzero weak-mixing coefficient ξ will result in a slight deviation from a purely electromagnetic polarization angle $\chi_0^{\rm em} = 0^\circ$ or 90°, respectively. An accurate measurement of the *orientation* of the photon polarization axis in the RR into the $2\,^3P_0$ state may provide, therefore, a direct access to the atomic parity-violation parameters and especially the Weinberg angle θ_W.

III. RESULTS AND DISCUSSION

The parity mixing (6) is inversely proportional to the energy difference $\Delta E = E_{2\,^3P_0} - E_{2\,^1S_0}$ and, hence, is strongly enhanced for those elements, for which the $2\,^1S_0$ and $2\,^3P_0$ levels are (nearly) degenerate. For the helium isoelectronic sequence, there are two level crossings near to $Z \approx 64$ and $Z \approx 90$ [40,41]. In the present work, we focus on the first crossing and investigate the PNC effects for the radiative recombination of the gadolinium $^{152}Gd^{62+}$ ion whose level scheme is shown in Fig. 1. The energy splitting between the $2\,^1S_0$ and $2\,^3P_0$ states of such an ion is $\Delta E = -0.03(3)$ eV, which is more than an order of magnitude larger than the corresponding natural line widths. This value of ΔE was recently calculated within the framework of the relativistic many-body perturbation theory (RMBPT) and by including the QED and recoil corrections [41]. Even though the achieved theoretical accuracy is still not very high, a more precise determination of the ΔE is likely to be performed experimentally in forthcoming years with the help of (two-photon) laser spectroscopy.

Using the theoretical value of the $2\,^1S_0$–$2\,^3P_0$ energy splitting, the best estimate of $\sin^2\theta_W = 0.2312$ from Ref. [42], and a spherically symmetric Fermi radial distribution of the nuclear charge with the rms radius $\langle r^2\rangle^{1/2} = 5.08$ fm recommended by the author of Ref. [43], we found the mixing parameter (6) to be $|\xi| = 5.62 \times 10^{-6}$ for the $^{152}Gd^{62+}$ ion. This parameter has been employed then to compute the tilt angle (8) of the RR linear polarization for the electron capture into $2\,^3P_0$ ionic state. In Fig. 2 the $\chi_0 - \chi_0^{\rm em}$ (top panels) is displayed, together with the Stokes parameters (middle panels), and the RR differential cross section (bottom panels) for projectile energies $T_p = 100, 300,$ and 600 MeV/u. As seen from the figure, the PNC-induced rotation of the RR linear polarization reaches its maximum at the angles $\theta_{\rm crit}(T_p)$ where the "purely electromagnetic" Stokes parameter P_1 (solid line on the middle panels) turns to zero. These "critical" angles, however, are not of interest for the current investigations since

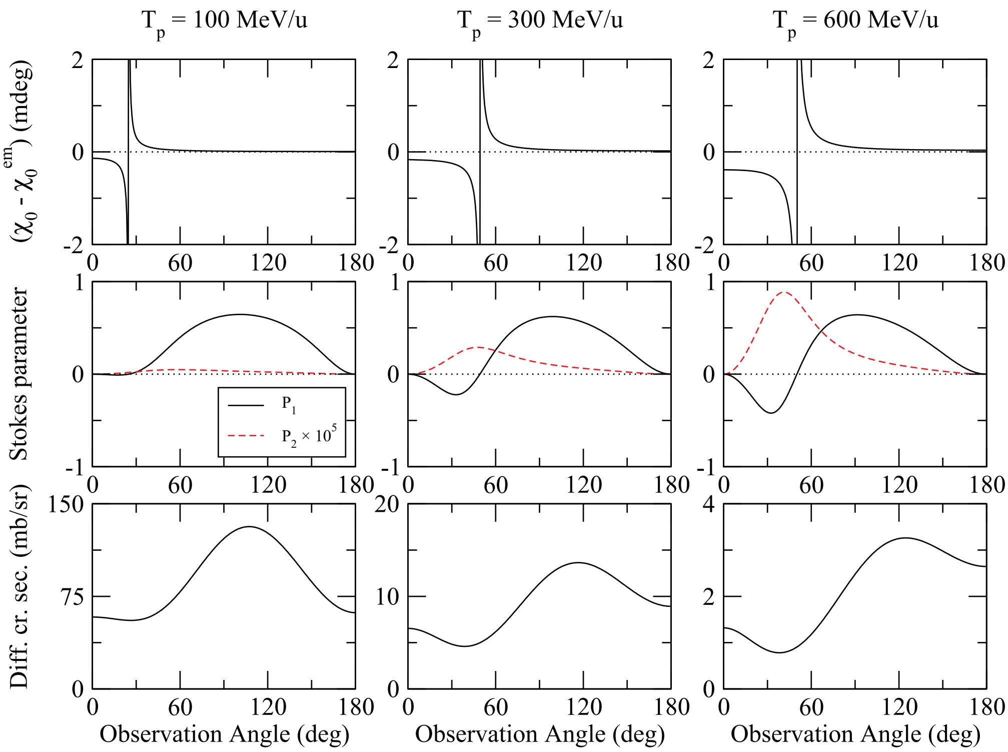

FIG. 2. (Color online) Tilt angle of the linear polarization (top panels), Stokes parameters P_1 and P_2 (middle panels), and differential cross section (bottom panels) for the RR of unpolarized electrons into the $2\,^3P_0$ state of finally helium-like $^{152}Gd^{62+}$ ions. Calculations for the projectile energies $T_p = 100$, 300, and 600 MeV/u are presented in the laboratory frame.

the (degree of) polarization $P_L = |P_2| = |\xi f_2(Z,T_p,\theta)| \ll 1$ is negligibly small at $\theta = \theta_{\rm crit}$ and cannot be observed by means of the available x-ray polarimeters. On the other hand, in the regions of the forward ($0^\circ < \theta < \theta_{\rm crit}$, where $P_1 < 0$ and $\chi_0^{\rm em} = 90^\circ$) and "central" ($\theta_{\rm crit} < \theta \lesssim 120^\circ$, where $P_1 > 0$ and $\chi_0^{\rm em} = 0^\circ$) photon emission the polarization as well as the photon yield become large enough and favor studies of the weak electron-nucleus interaction. While, for example, the linear polarization of the RR is tilted counterclockwise with respect to the (direction perpendicular to the) reaction plane for an emission in the forward direction $\chi_0 - \chi_0^{\rm em} = \chi_0 - 90^\circ < 0$, the same weak electron–nucleus interaction results in a clockwise rotation, $\chi_0 - \chi_0^{\rm em} = \chi_0 - 0^\circ > 0$, for central angles $\theta \approx 60$–120°. In both cases, the tilt angle increases with the collision energy and may reach 0.5 mdeg for $T_p = 600$ MeV/u.

While for $^{152}Gd^{62+}$ ions and energies $T_p \lesssim 600$ MeV/u, which are available for present-day collision studies [38], the tilt angle does not exceed the sub-mdeg region, it may be further enhanced by (i) using other gadolinium isotopes as well as (ii) increasing projectile velocities. At the future Facility for Antiproton and Ion Research (FAIR) in Darmstadt, for example, experiments with $\sim$ 1–2 GeV/u heavy ions are planned to be carried out in the forthcoming decade. For such collision energies, the linear polarization properties of the $2\,^3P_0$-RR photons have been explored for $^{156}Gd^{62+}$ ions for which the energy splitting between $2\,^3P_0$ and $2\,^1S_0$ states is estimated to be $\Delta E = 0.002(30)$ eV [41], about *one order* of magnitude smaller than (theoretical prediction for) that of the $^{152}Gd^{62+}$ isotope. Together with the rms radius $\langle r^2\rangle^{1/2} = 5.15$ fm [43], this (rather small) splitting gives rise to a parity-mixing parameter $|\xi| = 8.7 \times 10^{-5}$, which was utilized for the computations in Fig. 3. Again, we here display not only the Stokes parameters and the angular distribution of the recombination photons, but also the PNC-induced tilt angle $\Delta\chi_{\rm PNC}$ of the $2\,^3P_0$-RR linear polarization. As seen from the figure, this angle is positive in the forward scattering region and negative for $\theta > \theta_{\rm crit}$; in contrast to what is observed for the electron capture by $^{152}Gd^{62+}$ ions (cf. Fig. 2). Such a qualitative difference merely reflects the reverse sequence of the $2\,^1S_0$ and $2\,^3P_0$ levels in the $^{152}Gd^{62+}$ and $^{156}Gd^{62+}$ ions [41] and, hence, the opposite sign of the corresponding mixing parameters (6).

The comparison of the upper panels in Figs. 2 and 3 suggests that the absolute value $|\Delta\chi_{\rm PNC}|$ is enhanced as expected, if ^{156}Gd isotopes are employed and accelerated to high velocities for the polarization studies on the radiative electron capture into initially hydrogen-like ions. For a collision energy of $T_p = 2$ GeV/u, for example, the tilt angle reaches about 25 mdeg if the recombination photons are observed in the angular range $15^\circ \lesssim \theta \lesssim 25^\circ$. Over this range, the $\Delta\chi_{\rm PNC}$ remains large and almost constant and, hence, favors the application of the modern x-ray polarization sensitive segmented detectors. Today, these detectors allow to achieve an x-ray angular resolution of the order of 1° in a typical experiment with a stored beam and a gas target. Moreover, for the forward emission, $\theta > 20^\circ$, the degree of the $2\,^3P_0$-RR linear polarization is very high, reaching $P_L \approx 50$–60% thus also increasing the statistical sensitivity of the potential experiment. On the other hand, one may recognize from the bottom panel of Fig. 3 that in the same

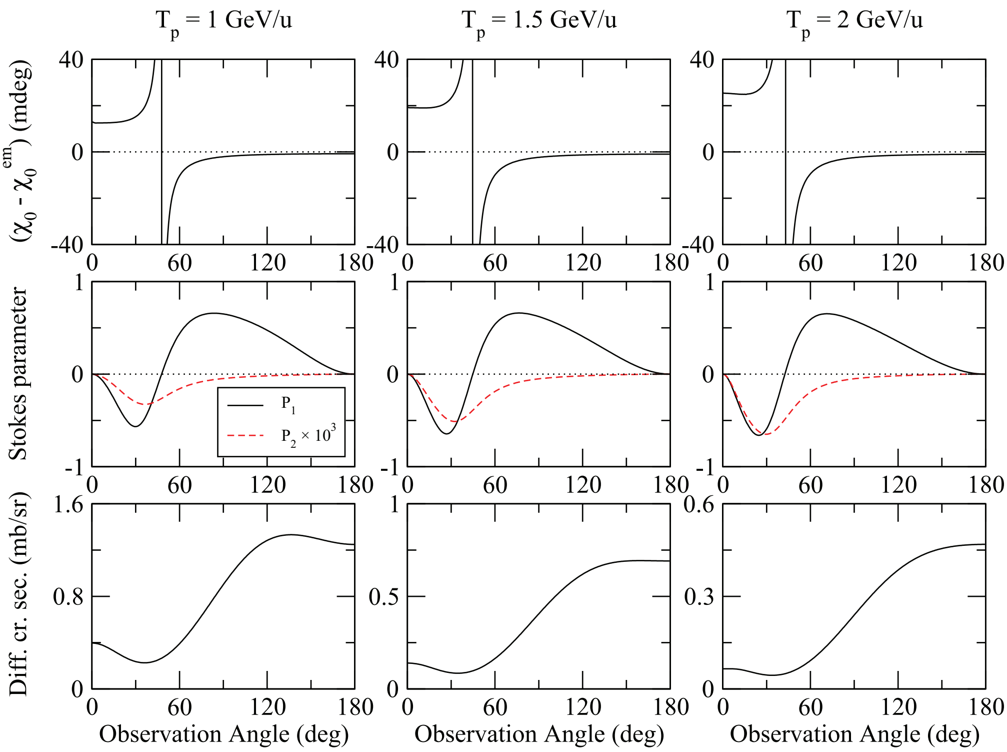

FIG. 3. (Color online) The same as Fig. 2 but for the RR of electrons into the $2\,^3P_0$ state of finally helium-like $^{156}Gd^{62+}$ ions moving with energies $T_p = 1$, 1.5, and 2 GeV/u.

angular range and for GeV/u collision energies, the RR cross section falls to about 0.1 mbarn/sr. This small cross section can be compensated for only by a large ion beam intensity and the target density. In the high-energy storage ring (HESR) at the future FAIR facility, for example, beams with up to 10^9 ions will be stored with the revolution frequency of 10^6 Hz. When studying the collisions of these beams with gas or microdroplet targets, whose (quasifree electron) densities can reach 10^{15} electrons/cm^{-3}, one can estimate an event rate of about 100 sr^{-1}s^{-1} or 6×10^7 events per week in a detector array covering 1 steradian. Recently, the data with a hundred times smaller statistics has been allowed to reach the (polarization-) angle resolution of 0.3° in the measurements of bremsstrahlung radiation whose degree of polarization did not exceed 50% [29,31]. Hence, it seems feasible to achieve a statistical uncertainty of 0.02° or better already in the near future, especially by using large solid angle detector arrays like the Advance Gamma Tracking Array (AGATA) [44], doing longer measurements, and employing targets of higher densities, based on fibers or foils.

In the present work, we have restricted our theoretical analysis to the electron capture into the single $2\,^3P_0$ state, for which the PNC effect is significantly larger than for the recombination into the $2\,^1S_0$ state. However, owing to the restricted energy resolution of modern polarization detectors, the photons emitted in the RR into these (almost degenerate) levels cannot be distinguished experimentally. If no method is applied to *single out* one of the recombination channels, therefore, the superposition $2\,^1S_0$- and $2\,^3P_0$–RR x rays will be observed. The linear polarization of such a superposition can be described in terms of "effective" Stokes parameters given by [45]

$$P_i^{\rm eff} = \frac{\frac{d\sigma}{d\Omega}(2\,^1S_0)P_i(2\,^1S_0) + \frac{d\sigma}{d\Omega}(2\,^3P_0)P_i(2\,^3P_0)}{\frac{d\sigma}{d\Omega}(2\,^1S_0) + \frac{d\sigma}{d\Omega}(2\,^3P_0)}, \quad (9)$$

where $i = 1,2$, and $\frac{d\sigma}{d\Omega}$ is the angle-differential cross section for the electron capture into the corresponding state. Our fully relativistic calculations have indicated that due to the opposite signs of $P_2(2\,^1S_0)$ and $P_2(2\,^3P_0)$ in Eq. (9), the effective second Stokes parameter $P_2^{\rm eff}$ and, hence, the (effective) tilt angle $\Delta\chi_{\rm PNC}^{\rm eff} \sim P_2^{\rm eff}/P_1^{\rm eff}$ become negligibly small. For the electron recombination into $2\,^1S_0$ and $2\,^3P_0$ states of finally $^{156}Gd^{62+}$ projectiles moving with energy $T_p = 2$ GeV/u, for example, $\Delta\chi_{\rm PNC}^{\rm eff}$ hardly exceeds 0.3 mdeg which is about two orders of magnitude smaller than the rotation angle of the $2\,^3P_0$-RR radiation. Hence, the $2\,^1S_0$-RR channel smears out the discussed parity-violating effects and need to be cutoff, for instance, by performing a *coincidence* measurement of the $2\,^3P_0$-recombination and subsequent-decay photons. Owing to the fact that the lifetime of the $2\,^3P_0$ state considerably exceeds the one of the $2\,^1S_0$ state (as well as of all near-lying levels), the time-delayed measurement of the characteristic $2\,^3P_0 \to 2\,^3S_1$ ($E1$) or $2\,^3S_1 \to 1\,^1S_0$ ($M1$) line will provide a unique signature of the RR into the $2\,^3P_0$, thereby making the proposed scheme feasible.

IV. SUMMARY

In conclusion, the influence of the electron–nucleus weak interaction on the polarization properties of the RR photons is investigated within the framework of the density matrix theory and the frozen-core Dirac-Fock approximation. For the capture of unpolarized electrons into the $2\,^3P_0$ state of helium-like ions, in particular, the PNC-induced mixing with the near-degenerate $2\,^1S_0$ level is predicted to induce the tilt of the RR linear polarization out of the reaction plane (or from the direction perpendicular to this plane). We found that the tilt angle is directly proportional to the $2\,^1S_0$–$2\,^3P_0$ mixing parameter and, hence, its measurements may serve as a promising tool for studying atomic PNC phenomena in the high-Z regime. Based on the calculations, performed for the radiative recombination of $^{152}Gd^{62+}$ and $^{156}Gd^{62+}$ ions we argue that such measurements may become feasible in the future.

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