Parity nonconservation in the radiative recombination of electrons with heavy hydrogen-like ions

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Abstract

The parity nonconservation effect on the radiative recombination of electrons with heavy hydrogen-like ions is studied. Calculations are performed for the recombination into the $2^1S_0$ state of helium-like thorium and gadolinium, where, due to the near-degeneracy of the opposite-parity $2^1S_0$ and $2^3P_0$ states, the effect is strongly enhanced. Two scenarios for possible experiments are studied. In the first scenario, the electron beam is assumed to be fully polarized while the H-like ions are unpolarized, and the polarization of the emitted photons is not detected. In the second scenario, the linearly polarized photons are detected in an experiment with unpolarized electrons and ions. Corresponding calculations for the recombination into the $2^3P_0$ state are presented as well. (Some figures in this article are in colour only in the electronic version)

1. Introduction

Investigations of the parity nonconservation (PNC) effects in atoms remain an effective tool for tests of the standard model (SM) and its various extensions [1–3]. High-precision measurement of the $6s–7s$ PNC amplitude in $^{133}$Cs [4, 5], combined with the recent progress on the QED and atomic-structure calculations [6–15], provided the most accurate to-date test of the electroweak sector of the SM at the low-energy regime. From the theoretical side, one of the main difficulties in calculations of the PNC effects in neutral atoms consists in the high-precision evaluation of the electron-correlation contributions (see [15] and references therein). This problem disappears if one deals with few-electron highly charged ions, where the electron-correlation effects, being suppressed by a factor $1/Z$ ($Z$ is the nuclear charge number), can be evaluated by perturbation theory to the required accuracy.

The PNC effects in highly charged ions were first discussed by Gorshkov and Labzowsky in [16], where a proposal to use close opposite-parity levels $2^1S_0$ and $2^3P_1$ for $Z \approx 6$ and $Z \approx 29$ was made. An idea for detecting parity violation in He-like ions with $Z \approx 6$ by investigating the induced $2^3S_1–2^1S_0$ transition in the presence of electric and magnetic fields was considered by von Oppen [17]. Various scenarios for observing the PNC effect in He-like uranium using the near-degeneracy of the $2^1S_0$ and $2^3P_0$ states were discussed in [18–20]. Schäfer et al [18] estimated the laser intensities required to observe the PNC asymmetry in the two-photon $2^3P_0–2^1S_0$ transition. Karasiev et al [19] evaluated the degree of circular polarization of photons emitted in the hyperfine-quenched one-photon $2^1S_0–1^1S_0$ transition. An idea to study the PNC effect on the two-photon $2^3P_0–1^1S_0$ transition, stimulated by the circularly polarized optical laser, was proposed by Dunford [20]. PNC experiments with polarized ion beams at $Z \approx 64$, where the $2^1S_0$ and $2^3P_0$ states of He-like ions are also near degenerate, were suggested by Labzowsky et al [21]. As in [19], here the hyperfine-induced one-photon $2^1S_0–1^1S_0$ transition was considered. A detailed analysis of possibilities for the PNC experiments with heavy H-like ions was presented by Zolotarev and Budker [22]. The parity-violating effect on the Auger decay of doubly excited states of He-like uranium was examined by Pindzola.
[23]. In [24], Gribov et al have studied the PNC effect on the cross section of dielectronic recombination into doubly excited states of He-like ions at \( Z < 60 \).

In this paper, we study the PNC effect on the one-photon radiative recombination (RR) of an electron into the \( 2S_0 \) and the \( 2P_0 \) state of He-like ions nearby \( Z = 90 \) and \( Z = 64 \), where the opposite-parity states \( 2S_0 \) and \( 2P_0 \) are close to crossing.

Relativistic units (\( h = c = 1 \)) and the Heaviside charge unit (\( \alpha = e^2/(4\pi) \), \( e < 0 \)) are used throughout the paper.

2. Basic formulae

Theory of the radiative recombination of electrons with highly charged ions was considered by many authors [25–31]. In this paper, we consider the one-photon radiative recombination of an electron having the asymptotic four-momentum \( p_i = (p_i^0, \mathbf{p}) \) and the spin projection \( \mu_i \) with a heavy H-like ion being originally in the 1s ground state. Here—and in what follows—it is assumed that the momentum \( \mathbf{p} \) is directed along the quantization axis (z-axis).

Since we are interested in the PNC effect, we consider that the electron is captured into the \( 2S_0 \) (or, alternatively, \( 2P_0 \)) state of a heavy He-like ion with \( Z \approx 90 \) or \( Z \approx 64 \), where the opposite-parity states \( 2S_0 \) and \( 2P_0 \) are near degenerate. This capture is accompanied by the emission of a photon with momentum \( \mathbf{k} \), energy \( E_k^0 = |k| = p_i^0 - E_{2S_0} \), and polarization \( \epsilon^\nu = (0, \epsilon) \). To zeroth order, the cross section of the process is given by [26]

\[
\frac{d\sigma}{d\Omega} = \frac{(2\pi)^4}{v_i} |\langle f | R^1(1) + R^2(2)i | i \rangle|^2,
\]

where \( |i\rangle \) and \( |f\rangle \) denote the initial and final states of the two-electron system, \( R = -e\alpha \cdot \mathbf{A} \) is the transition operator acting on the electron variables labelled in equation (1) by the indices 1 and 2, respectively,

\[
A(x) = \frac{\epsilon \exp(ik \cdot x)}{\sqrt{2v_i^0(2\pi)^3}},
\]

is the wavefunction of the emitted photon, and \( v_i \) is the initial electron velocity. Since for heavy few-electron ions the interelectronic-interaction effects are suppressed by a factor \( 1/Z \), compared to the electron–nucleus Coulomb interaction, we can consider the wavefunctions of the initial and final states in the one-electron approximation. The uncertainty due to neglecting the interelectronic-interaction and QED corrections should not exceed a few percent level [32–34].

With this approximation, the initial state is described by the wavefunction

\[
u_i(x_1, x_2) = \frac{1}{\sqrt{2}}(\psi_{j,m_1}(x_1)\psi_{p,\mu_1}(x_2) - \psi_{j,m_2}(x_2)\psi_{p,\mu_1}(x_1)),
\]

where \( \psi_{j,m}(x) \) is the one-electron 1s wavefunction and \( \psi_{p,\mu}(x) \) is the incident electron wavefunction. If we neglect the interelectronic and the weak electron–nucleus–interaction, the wavefunction of the final (\( 2S_0 \) or \( 2P_0 \)) state is given by

\[
u_f(x_1, x_2) = \frac{1}{\sqrt{2}} \sum_{m_1, m_2} C_{j,m_1,j,m_2}^{00}(\psi_{j,m_1}(x_1)\psi_{j,m_2}(x_2) - \psi_{j,m_2}(x_2)\psi_{j,m_1}(x_1)),
\]

where \( \psi_{j,m_i}(x) \) is the one-electron 1s wavefunction, \( \psi_{j,m_i}(x) \) is the one-electron 2s (\( 2p_{1/2} \)) wavefunction and \( C_{j,m_1,j,m_2}^{FM} \) is the Clebsch–Gordan coefficient. To account for the weak interaction, we must modify the wavefunction of the \( 2S_0 \) (\( 2P_0 \)) state by admixing the \( 23P_0 \) (\( 21S_0 \)) state. This yields

\[
|21S_0\rangle \rightarrow |21S_0\rangle + \frac{(21P_0|H_W(1) + H_W(2)|21S_0\rangle)}{E_{2S_0} - E_{2P_0}}|21P_0\rangle,
\]

\[
|21P_0\rangle \rightarrow |21P_0\rangle + \frac{(21S_0|H_W(1) + H_W(2)|21P_0\rangle)}{E_{2P_0} - E_{2S_0}}|21S_0\rangle,
\]

where

\[
H_W = -(G_F/\sqrt{8})Q_W\rho_N(r)\gamma_5
\]

is the nuclear spin-independent weak-interaction Hamiltonian [1], \( G_F \) is the Fermi constant, \( Q_W \approx -N + Z(1 - 4\sin^2\theta_W) \) is the weak charge of the nucleus, \( \gamma_5 \) is the Dirac matrix and \( \rho_N \) is the nuclear weak-charge density normalized to unity. A simple evaluation of the weak-interaction matrix element gives

\[
\langle 21P_0|H_W(1) + H_W(2)|21S_0\rangle = \langle 2p_{1/2}|H_W(2s)\rangle
\]

\[
= i \frac{G_F}{2\sqrt{2}} \frac{Q_W}{\sqrt{E_{2S_0} - E_{2P_0}}} \int_0^\infty dr r^2 \rho_N(r)[g_{2p_{1/2}}f_{2s} - f_{2p_{1/2}}g_{2s}].
\]

The large and small radial components of the Dirac wavefunction, \( g(r) \) and \( f(r) \), are defined by

\[
\psi_{n\kappa\mu}(r) = \left( \frac{g_{n\kappa}(r)}{f_{n\kappa}(r)} \right) \left( \frac{\Omega_{\kappa\mu}(n)}{\Omega_{n\mu}(\kappa)} \right),
\]

where \( k = (-1)^{\kappa+1/2}(j + 1/2) \) is the Dirac quantum number. Then formulae (5)–(6) can be written as

\[
|21S_0\rangle \rightarrow |21S_0\rangle + i\frac{\xi}{\sqrt{2}}|21P_0\rangle,
\]

\[
|21P_0\rangle \rightarrow |21P_0\rangle + i\frac{\xi}{\sqrt{2}}|21S_0\rangle,
\]

where

\[
\xi = \frac{G_F}{2\sqrt{2}} \frac{Q_W}{\sqrt{E_{2S_0} - E_{2P_0}}} \int_0^\infty dr r^2 \rho_N(r)[g_{2p_{1/2}}f_{2s} - f_{2p_{1/2}}g_{2s}].
\]

With this correction, the differential cross section of recombination into the \( 2S_0 \) state, \( \sigma \equiv d\sigma/d\Omega \), can be written in terms of the one-electron matrix elements:

\[
\sigma = \frac{1}{2} \frac{(2\pi)^4}{v_i} \left| k^2 \left( |(2s - m)R^1|p_i|\mu_i\rangle \right) \right|^2
\]

\[
+ 2\pi i \frac{\xi}{2}\left( 2s - m \right) \left| p_i|\mu_i\rangle \langle p_i|\mu_i\rangle R \left( 2p_{1/2} - m \right) \right|,
\]

where \( m \) is the angular momentum projection of the initial 1s electron. The corresponding expression for the recombination into the \( 2P_0 \) state is given by

\[
\sigma = \frac{1}{2} \frac{(2\pi)^4}{v_i} \left| k^2 \left( |(2p_{1/2} - m)R^1|p_i|\mu_i\rangle \right) \right|^2
\]

\[
+ 2\pi i \frac{\xi}{2}\left( 2p_{1/2} - m \right) \left| p_i|\mu_i\rangle \langle p_i|\mu_i\rangle R \left( 2s - m \right) \right|.
\]

The incoming electron wavefunction is given by the partial wave expansion

\[
|p_i|\mu_i\rangle = \frac{1}{\sqrt{4\pi}} \frac{1}{\sqrt{|p_i|\mu_i}} \sum_k \exp(i\Delta_k)
\]

\[
\times \sqrt{2l + 1} C^{\mu_i}_{l,0,\frac{1}{2}m_i} |\xi| \kappa |\mu_i\rangle,
\]

where \( C^{\mu_i}_{l,m_1,m_2} \) is the Clebsch–Gordan coefficient.
where $\Delta_\kappa$ is the Coulomb phase shift and $|\epsilon, \kappa \mu_i\rangle$ is the partial electron wave with the energy $\epsilon_i = p_i^0$ and the Dirac quantum number $\kappa$. This expansion enables one to express the free-bound transition amplitude as a sum of partial amplitudes

$$
\langle p_1 \mu_1 | R | n_b j_b \mu_b \rangle = \frac{1}{\sqrt{4\pi}} \frac{1}{\sqrt{p_i \epsilon_i}} \times \sum_{\kappa} \langle \kappa \epsilon \mu_i | R | n_b j_b \mu_b \rangle .
$$

The latter amplitude is evaluated employing the standard partial wave decomposition for the photon wavefunction (see, e.g., [30, 35]). The angular integrations are carried out analytically while the radial integrations are accomplished numerically. The RADIAL package [36] is used to calculate the bound and continuum wavefunctions for extended nuclei.

### 3. Results and discussion

The formulæ (13)–(14) represent the differential cross section at given values of the bound-electron angular momentum projection $m$, the incoming electron polarization $\mu_i$, and the outgoing photon polarization $\epsilon$. To investigate the role of the PNC effect, we consider two different scenarios for an experiment. In the first scenario, the incident electron is polarized, while the H-like ion is unpolarized, and the photon polarization is not detected. In this scenario, the cross sections (13)–(14) must be averaged over the bound-electron angular momentum projection $m$ and summed over the outgoing photon polarization $\epsilon$. Since recent advances in polarization techniques [37, 38] make measurements of the linear polarization of x-rays feasible, as the second one we consider a scenario, in which linearly polarized photons are detected in an experiment with unpolarized electrons and ions. In this scenario, we have to average over $m$ and $\mu_i$, and consider the photon linearly polarized under the angle $\chi$ with respect to the reference plane that is spanned by the incident electron and the emitted photon momenta (figure 1).

Since we are interested in observing the PNC effects, we should search for situations where these effects are enhanced as much as possible. As indicated above, the most promising situation occurs in cases where the $2^1S_0$ and $2^3P_0$ levels almost cross. The ions with $Z \approx 90$ and $Z \approx 64$ are presently considered as the best candidates for that. In table 1, we list the theoretical predictions for the $2^3P_0 \rightarrow 2^1S_0$ energy difference in ions near the crossing points [39, 40]. Compared to [39], these data are obtained using the revised values of the nuclear charge radii for $^{238}\text{U}$ and $^{232}\text{Th}$ [40, 41] as well as recent results for the two-loop QED contributions [42]. As seen from the table, the maximum enhancement takes place in the cases of Th and Gd. Although the current theoretical accuracy is not high enough, one can expect that the energy differences considered can be determined to the desired accuracy in an experiment [43]. In accordance with the table, to estimate the PNC effect we use 0.44 eV and 0.074 eV for the $2^3P_0 \rightarrow 2^1S_0$ energy difference in the cases of Th and Gd, respectively. We note that in both cases the energy differences utilized are significantly larger than the corresponding natural line widths.

As the next step, one should determine the sensitivity requirements for an experimental apparatus capable of observing the PNC effect to a given accuracy. Let us consider these requirements for the first experimental scenario with a fully polarized electron beam. Denoting by $\sigma_\kappa(\theta)$ and $\sigma_\kappa(\theta)$ the cross sections for the positive and negative helicities (the spin projection onto the electron momentum direction) of the incident electron, we can write for the related numbers of counts

$$
N_\kappa = LT(\sigma_\kappa + \sigma_\kappa),
$$

where $\sigma_\kappa$ is the background magnitude, $T$ is the acquisition time and $L$ is the luminosity defined by the experimental conditions. Let us assume that we want to measure the PNC effect with a relative uncertainty $\eta$. Then, taking into account that the statistical error of $N_+ - N_-$ is given by $\sqrt{N_+ + N_-}$, one derives the following requirement for the luminosity (cf [24]):

$$
L > L_0 = \frac{\sigma_+ + \sigma_- + 2\sigma_{\kappa}}{\sigma_+ - \sigma_-)\eta^2T}.
$$

For the following analysis, we neglect the background signal $\sigma_\kappa$ and assume that the acquisition time $T$ is equal to 2 weeks.

We calculated $L_0$ for different inclination angles $\theta$ and different incident electron energies. Table 2 presents numerical results for the radiative recombination into the $2^1S_0$ and the $2^3P_0$ state of He-like thorium at the angles $\theta$ corresponding to the minimum values of the luminosity $L_0$. For completeness, the cross section without the PNC effect, $\sigma_0 = (\sigma_+ + \sigma_-)/2$, and the PNC contribution, $\sigma_{\kappa} = (\sigma_+ - \sigma_-)/2$, are presented as well. In figures 2 and 3, we display the values $\sigma_{\kappa}/\sigma_0 \sim 1/L_0$ as functions of $\theta$ for the radiative recombination into the $2^1S_0$ and the $2^3P_0$ state, respectively, at the incident electron energy of 1 eV.

Tables 3 and 4 present numerical results for the second scenario, where linearly polarized photons are detected in an experiment with unpolarized electrons and ions. As before, $\sigma_0$ denotes the cross section without the PNC effect and $\sigma_{\kappa}$ is the PNC contribution. Again, the angles $\theta$ and $\chi$ considered in tables 3 and 4 correspond to the minimum values of the luminosity. In this scenario, the sign of the PNC contribution $\sigma_{\kappa}$ can be replaced by $\pi - \chi$. 

![Figure 1. Geometry (in the ion rest frame) for one-photon radiative recombination of a free electron into an excited state of a projectile ion. The unit vector of the linear polarization of the photon is defined in the plane that is perpendicular to the photon momentum.](image)
The 2^3P_0–2^1S_0 energy difference in He-like ions near the crossing points [39, 40], in eV.

Table 1. The 2^3P_0–2^1S_0 energy difference in He-like ions near the crossing points [39, 40], in eV.

| EU (Z = 63) | Gd (Z = 64) | Tb (Z = 65) | Dy (Z = 66) | Ac (Z = 89) | Th (Z = 90) | Pa (Z = 91) | U (Z = 92) |
|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| −0.249(69)  | −0.023(74)  | 0.29(12)    | 0.462(84)   | 1.52(40)    | 0.44(40)    | −0.43(50)   | −2.81(8)    |

The 2^3P_0–2^1S_0 energy difference in He-like ions near the crossing points [39, 40], in eV.

Table 2. Numerical results for the radiative recombination into the 2^1S_0 and the 2^3P_0 state of He-like thorium at the inclination angles θ corresponding to the minimum values of the luminosity L_0. The calculations are performed for the scenario, where the linearly polarized photons are detected in the experiment with unpolarized electrons and ions. L_0 is the luminosity defined by equation (18) at T = 2 weeks, σ_0 = (σ_+ + σ_-)/2 is the cross section without the PNC effect and σ_{PNC} = (σ_+ − σ_-)/2 is the PNC contribution.

| p_i^0 (keV) | θ (grad) | χ (grad) | L_0 (cm^2 s^-1) | σ_0 (barn) | σ_{PNC} (barn) |
|-------------|----------|----------|-----------------|------------|----------------|
| 0.001       | 180      | 9.1 × 10^{26} | 4281.8         | 0.14       |                |
| 0.005       | 0        | 4.5 × 10^{27} | 530.59         | 0.022      |                |
| 0.010       | 0        | 8.9 × 10^{27} | 265.22         | 0.011      |                |
| 0.050       | 0        | 4.3 × 10^{28} | 52.963         | 0.0023     |                |
| 0.100       | 0        | 8.3 × 10^{28} | 26.440         | 0.0011     |                |
| 0.500       | 0        | 3.8 × 10^{29} | 5.2346         | 0.00024    |                |
| 1.000       | 0        | 7.0 × 10^{29} | 2.5881         | 0.00012    |                |
| 5.000       | 0        | 3.0 × 10^{10} | 0.47949        | 2.6 × 10^{-5} |                |
| 20.000      | 0        | 1.1 × 10^{11} | 0.094911       | 6.0 × 10^{-6} |                |

The 2^3P_0–2^1S_0 energy difference in He-like ions near the crossing points [39, 40], in eV.

Table 3. Numerical results for the radiative recombination into the 2^1S_0 state of He-like thorium at angles θ and χ corresponding to the minimum values of the luminosity L_0. The calculations are performed for the scenario, where the linearly polarized photons are detected in the experiment with unpolarized electrons and ions. L_0 is the luminosity defined by equation (18) at T = 2 weeks, σ_0 = (σ_+ + σ_-)/2 is the cross section without the PNC effect and σ_{PNC} is the PNC contribution, which changes the sign under the replacement χ → π − χ.

| p_i^0 (keV) | θ (grad) | χ (grad) | L_0 (cm^2 s^-1) | σ_0 (barn) | σ_{PNC} (barn) |
|-------------|----------|----------|-----------------|------------|----------------|
| 0.001       | 94       | 68       | 3.0 × 10^{29}   | 10858.0    | 0.012          |
| 0.005       | 94       | 68       | 1.5 × 10^{30}   | 2171.3     | 0.0024         |
| 0.010       | 93       | 68       | 3.0 × 10^{30}   | 1087.2     | 0.0012         |
| 0.050       | 92       | 68       | 1.5 × 10^{31}   | 217.57     | 0.00025        |
| 0.100       | 91       | 68       | 2.9 × 10^{31}   | 108.82     | 0.00012        |
| 0.500       | 87       | 68       | 1.5 × 10^{32}   | 21.706     | 2.5 × 10^{-5}  |

The 2^3P_0–2^1S_0 energy difference in He-like ions near the crossing points [39, 40], in eV.

Table 4. Numerical results in the case of the radiative recombination into the 2^3P_0 state of He-like thorium at angles θ and χ corresponding to the minimum values of the luminosity L_0. The calculations are performed for the scenario, where the linearly polarized photons are detected in the experiment with unpolarized electrons and ions. L_0 is the luminosity defined by equation (18) at T = 2 weeks, σ_0 is the cross section without the PNC effect and σ_{PNC} is the PNC contribution, which changes the sign under the replacement χ → π − χ.

| p_i^0 (keV) | θ (grad) | χ (grad) | L_0 (cm^2 s^-1) | σ_0 (barn) | σ_{PNC} (barn) |
|-------------|----------|----------|-----------------|------------|----------------|
| 0.001       | 93       | 60       | 5.5 × 10^{29}   | 31208.0    | −0.015         |
| 0.005       | 92       | 60       | 2.8 × 10^{30}   | 6235.4     | −0.0031        |
| 0.010       | 92       | 60       | 5.5 × 10^{30}   | 3116.4     | −0.0015        |
| 0.050       | 91       | 60       | 2.7 × 10^{31}   | 621.76     | −0.00031       |
| 0.100       | 91       | 60       | 5.4 × 10^{31}   | 310.28     | −0.00015       |
| 0.500       | 88       | 60       | 2.6 × 10^{32}   | 61.426     | −3.1 × 10^{-5} |

The 2^3P_0–2^1S_0 energy difference in He-like ions near the crossing points [39, 40], in eV.

Table 5. Numerical results for the radiative recombination into the 2^1S_0 and the 2^3P_0 state of He-like thorium at angles θ and χ corresponding to the maximum absolute values of the PNC contribution σ_{PNC}. The calculations are performed for the scenario, where the linearly polarized photons are detected in the experiment with unpolarized electrons and ions. The σ_{PNC} contribution changes the sign under the replacement χ → π − χ.

| p_i^0 (keV) | θ (grad) | χ (grad) | RR into the 2^1S_0 state | RR into the 2^3P_0 state |
|-------------|----------|----------|--------------------------|--------------------------|
| 0.001       | 93       | 45       | 34440.018               | 5155.4                  |
| 0.005       | 93       | 45       | 6879.70035              | 10310.0                 |
| 0.010       | 92       | 45       | 3446.80018              | 5153.0                  |
| 0.050       | 92       | 45       | 688.690035              | 1030.1                  |
| 0.100       | 91       | 45       | 344.700018              | 514.60                  |
| 0.500       | 88       | 45       | 6894.000036             | 102.30                  |
to the maximum absolute values of $\sigma$ photon polarization is not detected. The electron is polarized while the H-like ion is unpolarized and the incident electron energy of 1 eV. It is assumed that the incoming photon polarization is not detected.

In figures 4 and 5, we display the value $\sigma_{\text{PNC}}^2/\sigma_0 \sim 1/L_0$ as a function of $\theta$ for the radiative recombination into the $2^1S_0$ state of He-like thorium at the incident electron energy of 1 eV. The change of the sign of the PNC contribution $\sigma_{\text{PNC}}$ under the replacement $\chi \rightarrow \pi - \chi$ means, in particular, that measuring the count rate difference between the two linear polarizations, which can be achieved in the same experiment by setting the detectors at different azimuth angles $\phi$, can provide a direct access to the pure PNC effect. With this in mind, in table 5 we present numerical results for the angles $\theta$ and $\chi$ corresponding to the maximum absolute values of $\sigma_{\text{PNC}}$. We note that the contribution $\sigma_{\text{PNC}}$ has the same absolute values but carries opposite signs for the radiative recombination into the $2^1S_0$ and the $2^3P_0$ state, respectively. It follows that the PNC effect disappears if one measures the cross section of the RR into both $2^1S_0$ and $2^3P_0$ states. To observe the PNC effect we need to detect the photons that originate from only one of these processes: either from the RR into the $2^1S_0$ state or from the RR into the $2^3P_0$ state. Although at present the experimental resolution is far from being sufficient to detect the desired transition line, we think that with some experimental ingenuity the blinding line could be eliminated. Alternatively, one might consider the same experiment at other values of $Z$, where the $2^3P_0-2^1S_0$ energy difference becomes larger while the PNC effect remains still sizeable.

The corresponding calculations have also been performed for the $^{158}\text{Gd}$ ion. It was found that, at the $2^3P_0-2^1S_0$ energy splitting of 0.074 eV, the PNC effect is smaller than that for thorium. In particular, in the first scenario for $p_0^i = 1$ eV the minimum luminosity for the RR into the $2^1S_0$ state amounts to $2.5 \times 10^{28} \text{ cm}^{-2} \text{ s}^{-1}$ at $\theta = 0$. The corresponding values of the cross section contributions are $\sigma_0 = 287.65 \text{ barn}$ and $\sigma_{\text{PNC}} = 0.0069 \text{ barn}$. In the second scenario, at the same kinetic electron energy, the minimum luminosity, $L_0 = 7.1 \times$
10^{11} \text{ cm}^{-2} \text{ s}^{-1}, has been found at the angles $\theta = 92$ and $\chi = 76$ with $\sigma_0 = 2429.3 \text{ barn}$ and $\sigma_{\text{PNC}} = 0.000 \text{ 38 barn}$. The maximum absolute value of the PNC contribution, reached at $\theta = 94$ and $\chi = 45$, amounts to $\sigma_{\text{PNC}} = 0.000 \text{ 80 barn}$ with $\sigma_0 = 19,488 \text{ barn}$.

4. Conclusion

In this paper, we investigated the PNC effect on the cross section of the radiative recombination of an electron into the $2^3S_0$ and $2^3P_0$ state of heavy He-like ions. The calculations were performed for the cases of thorium and gadolinium, where the PNC effect is strongly enhanced due to near degeneracy of the $2^3S_0$ and $2^3P_0$ states. Two scenarios of possible experiments were studied. It was found that a promising situation occurs in the scenario, where linearly polarized photons are detected in experiment with unpolarized electrons and ions, and the count rate difference between the two linear polarizations is measured simultaneously at different azimuth angles.

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