Influence of the Breit interaction on linear polarization of radiation lines following electron-impact excitation of the boron isoelectronic sequence

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Electron-impact excitation cross sections from the ground state $1s^22s^22p_{1/2}$ to the excited states $[(1s^22s2p_{1/2})_02p_{3/2}]_{3/2}$, $[(1s^22s2p_{3/2})_12p_{3/2}]_{5/2}$, $[(1s2s^22p_{1/2})_02p_{3/2}]_{3/2}$, and $[(1s2s^22p_{3/2})_12p_{3/2}]_{5/2}$ of highly charged boronlike Ca^{15+}, Xe^{49+}, and W^{69+} ions have been calculated with the fully relativistic distorted-wave method. The degrees of linear polarization of the corresponding radiation lines are further obtained. It is found that the Breit interaction makes the lines corresponding to the $2p \to 2s$ transition depolarized, and it makes the ones corresponding to the $2p \to 1s$ transition more polarized. These characteristics are very different from the results obtained for the linear polarization of the same radiation lines but formed via the dielectronic recombination process [Phys. Rev. A **91**, 042705 (2015)], in which the Breit interaction has no effect on the linear polarization.

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I. INTRODUCTION

Electron-impact excitation (EIE) of atoms or ions is one of fundamental atomic processes in astrophysical and laboratory plasmas. EIE cross sections and degrees of linear polarization of radiation lines following EIE processes have been widely applied for testing atomic structure theory, revealing atomic collision kinetics, predicting new phenomena, and so on [1–3]. When atoms or ions are excited by an electron beam or, more generally, by electrons with an anisotropic velocity distribution, magnetic sublevels of the produced excited states will be populated nonstatistically. As a consequence, the spectral lines radiated from these unequally populated sublevels to an energetically lower level become linearly polarized and anisotropic. The degree of linear polarization and anisotropy of these lines depend on the extent of deviation from the statistical populations of the excited magnetic sublevels. For this reason, the polarization and anisotropy can provide detailed information on both the incident electrons and collisional dynamics, based on which a very useful diagnostic tool has been developed to describe electron anisotropy in astrophysical and laboratory plasmas. Up to the present, this innovative tool has been applied to diagnose laser-produced plasmas [4–8], solar plasmas [9–11], Z pinches [12,13], and vacuum sparks [14,15], as well as to identify level splitting and sequence of overlapping resonances of neutral atoms or highly charged ions [16–18].

As we know already, the Breit interaction plays a very important role in fundamental atomic processes of highly charged ions with free electrons involved, which was first introduced by Breit in 1929 to describe relativistic effects in electron-electron interactions [19]. The Breit interaction consists of magnetic interactions and retardation effects in the exchange of a single virtual photon between a pair of electrons. In general, the magnetic interactions and retardation effects are so small that they are usually treated as minor corrections to the major term (i.e., the Coulomb interaction). However, the Breit interaction often significantly contributes to collision dynamics of highly charged ions with free electrons, and it can remarkably affect the collision strengths and cross sections of the dynamical process [20]. Therefore, for the collision processes of this kind, the Breit interaction between free electrons and bound electrons in target ions needs to be particularly considered.

Since the late 1980s, the Breit interaction has been considered in a systematic fashion and tested within a very high accuracy, especially in two-electron quantum electrodynamics (QED) calculations of heliumlike and lithiumlike ions [21,22]. A decade ago, Nakamura *et al.* [23] measured the effect of the Breit interaction on the resonant strengths of the dielectronic recombination of lithiumlike I^{50+}, Ho^{64+}, and Bi^{80+} ions in electron beam ion trap (EBIT) experiments. They found that the importance of the generalized Breit interaction on the dielectronic recombination increases as the atomic number increases. From then on, the investigation of the Breit interaction effect on various fundamental atomic processes has become more and more popular. Inspired by Nakamura's work [23], Fritzsche *et al.* [24] proposed theoretically an experimental scheme to extract the effect of the Breit interaction. In this proposal, they studied the degree of linear polarization and angular distribution of the $1s2s^22p_{1/2}J = 1 \to 1s^22s^2J = 0$ electric-dipole radiation of high-Z, beryllium-like ions, following the resonant electron capture into initially lithiumlike I^{50+}, Nd^{57+}, Ho^{64+}, W^{71+}, Bi^{80+}, and U^{89+} ions. It was found that the Breit interaction strongly dominates the Coulomb repulsion and leads to a qualitative change in the expected x-ray emission pattern. Before long, Hu *et al.* [25] confirmed experimentally the conclusion of Fritzsche *et al.* [24] in an EBIT measurement. Besides the above research work of the Breit interaction effect on the dielectronic recombination,

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TABLE I. The presently calculated excitation energies (in units of eV) from the ground state $1s^22s^22p_{1/2}$ to the $[(1s^22s2p_{1/2})_02p_{3/2}]_{3/2}$, $[(1s^22s2p_{1/2})_12p_{3/2}]_{5/2}$, $[(1s2s^22p_{1/2})_02p_{3/2}]_{3/2}$, and $[(1s2s^22p_{1/2})_12p_{3/2}]_{5/2}$ excited states of boronlike Ca^{15+}, Xe^{49+}, and W^{69+} ions with the use of models A, B, and C, respectively, together with other available results [33]. N stands for the results calculated with only the Coulomb interaction included, and B stands for the ones calculated with the inclusion of both the Coulomb and Breit interactions.

	Model A		Model B		Model C		Ref. [33]
	N	B	N	B	N	B	N
$1s^22s^22p_{1/2} \to [(1s^22s2p_{1/2})_02p_{3/2}]_{3/2}$							
Ca^{15+}	30.93	30.93	31.44	31.44	34.09	34.03	34.25
Xe^{49+}	474.14	472.27	473.10	472.02	471.09	470.07	471.71
W^{69+}	1673.61	1671.64	1662.99	1661.21	1653.71	1651.91	1653.60
$1s^22s^22p_{1/2} \to [(1s^22s2p_{1/2})_12p_{3/2}]_{5/2}$							
Ca^{15+}	33.41	33.17	33.93	33.69	36.46	36.25	36.52
Xe^{49+}	510.26	506.69	509.84	505.31	505.20	503.50	504.10
W^{69+}	1726.00	1712.99	1715.29	1711.48	1698.10	1693.23	1695.10
$1s^22s^22p_{1/2} \to [(1s2s^22p_{1/2})_02p_{3/2}]_{3/2}$							
Ca^{15+}	3802.06	3799.31	3798.81	3796.14	3804.90	3802.22	
Xe^{49+}	30 406.10	30 396.56	30 379.46	30 375.32	30 360.82	30 351.31	
W^{69+}	60 511.91	60 419.23	60 358.42	60 334.07	60 364.16	60 271.58	
$1s^22s^22p_{1/2} \to [(1s2s^22p_{1/2})_12p_{3/2}]_{5/2}$							
Ca^{15+}	3821.27	3817.87	3818.46	3815.06	3823.99	3820.62	
Xe^{49+}	30 433.76	30 359.87	30 406.73	30 328.04	30 388.40	30 314.82	
W^{69+}	60 551.29	60 346.42	60 428.89	60 266.68	60 403.45	60 204.04	

Wu *et al.* [26] investigated the effect of the Breit interaction on the linear polarization of x-ray emissions following the EIE of highly charged berylliumlike Mo^{38+}, Nd^{56+}, and Bi^{79+} ions. They found that the Breit interaction makes the x-ray emissions depolarized, and this character becomes more and more evident with increasing incident electron energy and nuclear charge number. Very recently, Jörg *et al.* [27] measured the degree of linear polarization of x-rays emitted via resonant electron capture into boronlike Xe^{49+} ions, which can be described schematically by

$$\varepsilon e + 1s^22s^2 \to [(1s2s^22p_{1/2})_02p_{3/2}]_{3/2} \to 1s^22s^22p_{1/2} + h\nu, \quad (1)$$

$$\varepsilon e + 1s^22s^2 \to [(1s2s^22p_{1/2})_12p_{3/2}]_{5/2} \to 1s^22s^22p_{3/2} + h\nu. \quad (2)$$

As above, they also discussed particularly the effect of the Breit interaction on the linear polarization of the x rays. It was found that the Breit interaction has no effect on the x-ray polarization, which is surprisingly different from the conclusions obtained above.

In the present work, for the same transition lines of highly charged boronlike Ca^{15+}, Xe^{49+}, and W^{69+} ions but formed by the EIE process:

$$\varepsilon e + 1s^22s^22p_{1/2} \to [(1s^22s2p_{1/2})_02p_{3/2}]_{3/2} + \varepsilon' e \to 1s^22s^22p_{1/2} + h\nu, \quad (3)$$

$$\varepsilon e + 1s^22s^22p_{1/2} \to [(1s^22s2p_{1/2})_12p_{3/2}]_{5/2} + \varepsilon' e \to 1s^22s^22p_{3/2} + h\nu, \quad (4)$$

TABLE II. The presently calculated EIE strengths from the ground state $1s^22s^22p_{1/2}$ to the $[(1s^22s2p_{1/2})_02p_{3/2}]_{3/2}$ and $[(1s^22s2p_{1/2})_12p_{3/2}]_{5/2}$ excited states of boronlike Ca^{15+}, Xe^{49+}, and W^{69+} ions at scattered electron energy $E' = 0.03$ in units of $(Z-3.33)^2$Ry together with other available results [33]. N+N denotes that both the target wave functions and impact matrix elements are calculated without the Breit interaction included, B+N denotes the former are calculated with an inclusion of the Breit interaction but the latter without the Breit interaction included, and B+B represents both of them are calculated with the Breit interaction included.

	$1s^22s^22p_{1/2} \to [(1s^22s2p_{1/2})_02p_{3/2}]_{3/2}$				$1s^22s^22p_{1/2} \to [(1s^22s2p_{1/2})_12p_{3/2}]_{5/2}$			
	N+N	B+N	B+B	Ref. [33]	N+N	B+N	B+B	Ref. [33]
Ca^{15+}	8.94[−3]	8.94[−3]	8.96[−3]	9.05[−3]	6.15[−3]	6.15[−3]	6.17[−3]	6.24[−3]
Xe^{49+}	1.55[−3]	1.55[−3]	1.57[−3]	1.57[−3]	1.44[−3]	1.44[−3]	1.47[−3]	1.44[−3]
W^{69+}	8.73[−4]	8.73[−4]	8.95[−4]	8.77[−4]	7.61[−4]	7.61[−4]	7.90[−4]	7.62[−4]

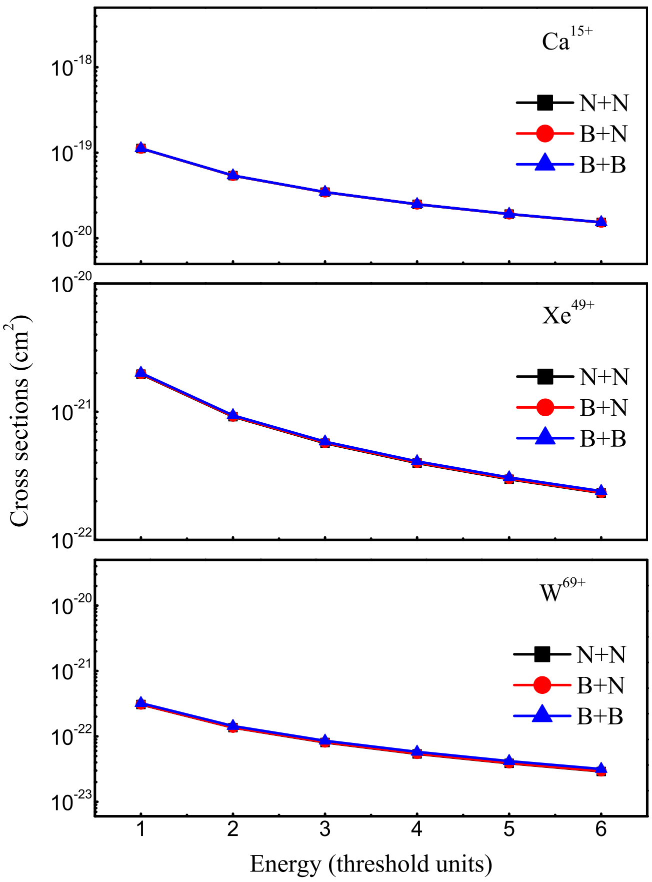

FIG. 1. Total EIE cross sections (cm^2) from the ground state $1s^22s^22p_{1/2}$ to the excited state $[(1s^22s2p_{1/2})_02p_{3/2}]_{3/2}$ of highly charged boronlike Ca^{15+}, Xe^{49+}, and W^{69+} ions as functions of incident electron energy in threshold units. N+N denotes that both the target wave functions and impact matrix elements are calculated without the Breit interaction included; B+N denotes the former are calculated with an inclusion of the Breit interaction but the latter without the Breit interaction included; B+B represents both of them are calculated with the Breit interaction included.

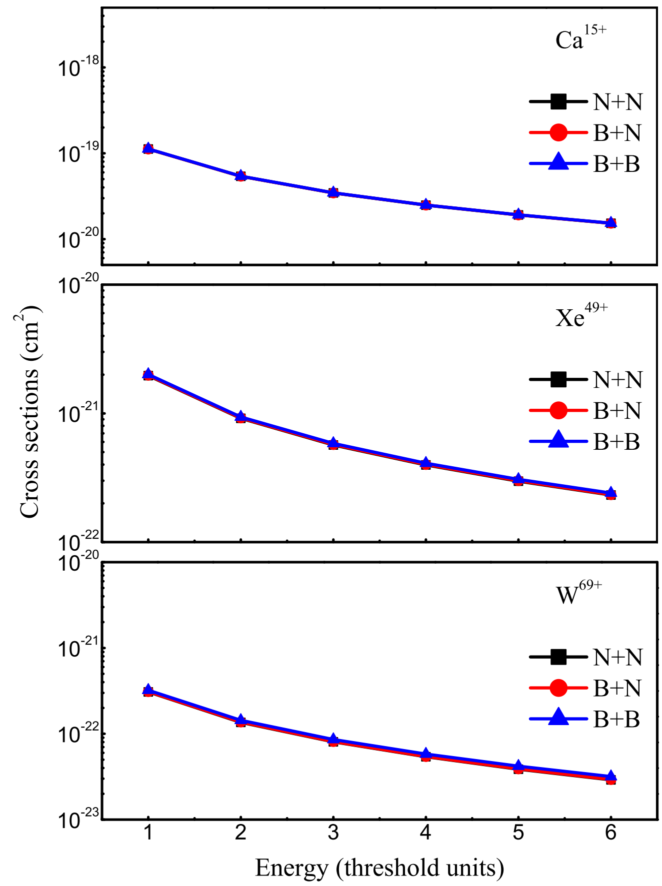

FIG. 2. The same as Fig. 1 but for the excitation to the excited state $[(1s^22s2p_{1/2})_12p_{3/2}]_{5/2}$.

$$\varepsilon e + 1s^22s^22p_{1/2} \rightarrow [(1s2s^22p_{1/2})_02p_{3/2}]_{3/2} + \varepsilon' e \rightarrow 1s^22s^22p_{1/2} + h\nu, \tag{5}$$

$$\varepsilon e + 1s^22s^22p_{1/2} \rightarrow [(1s2s^22p_{1/2})_12p_{3/2}]_{5/2} + \varepsilon' e \rightarrow 1s^22s^22p_{3/2} + h\nu, \tag{6}$$

the specific magnetic sublevel excitation cross sections and degree of linear polarization of the transition lines are calculated with the use of a fully relativistic distorted-wave computer program REIE06 [28]. Additionally, the influence of the Breit interaction on the excitation cross sections as well as the degree of linear polarization are discussed in detail.

This paper is structured as follows: In the next section, the theoretical methods for the calculations of the EIE cross sections and the degrees of linear polarization of x-ray emissions are presented. In Sec. III we discuss the calculated total EIE cross sections and the degrees of linear polarization of the corresponding emissions. Finally, a brief conclusion of the present work is given in Sec. IV. Atomic units ($m_e = 1, e = 1, \hbar = 1$) are used throughout this paper unless stated otherwise.

II. THEORETICAL METHOD

In the fully relativistic distorted-wave method, the EIE cross section of a target ion from its initial state $\beta_i J_i M_i$ to the final state $\beta_f J_f M_f$ can be written as [29,30]

$$\begin{aligned}\sigma_{\varepsilon_i}(\beta_i J_i M_i \rightarrow \beta_f J_f M_f) &= \frac{2\pi a_0^2}{k_i^2} \\ &\times \sum_{l_i, l_i', j_i, j_i', m_{s_i}, l_f, j_f, m_f} \sum_{J, J', M} (i)^{l_i - l_i'} \\ &\times [(2l_i+1)(2l_i'+1)]^{1/2} \exp[i(\delta_{\kappa_i} - \delta_{\kappa_i'})] \\ &\times C^{j_i m_i}_{l_i \frac{1}{2} m_{l_i} m_{s_i}} C^{j_i' m_i}_{l_i' \frac{1}{2} m_{l_i'} m_{s_i}} C^{JM}_{J_i j_i M_i m_i} \\ &\times C^{J'M}_{J_i j_i' M_i m_i} C^{JM}_{J_f j_f M_f m_f} C^{J'M}_{J_f j_f M_f m_f} \\ &\times R(\gamma_i, \gamma_f) R(\gamma_i', \gamma_f'),\end{aligned} \tag{7}$$

where the subscripts i and f refer to the initial and final states, respectively; ε_i is the incident electron energy in Rydbergs; a_0 is the Bohr radius; C denote Clebsch-Gordan coefficients; R are the collision matrix elements; $\gamma_i = \varepsilon_i l_i J_i \beta_i JM$ and $\gamma_f = \varepsilon_f l_f J_f \beta_f JM$; J and M denote, respectively, total angular

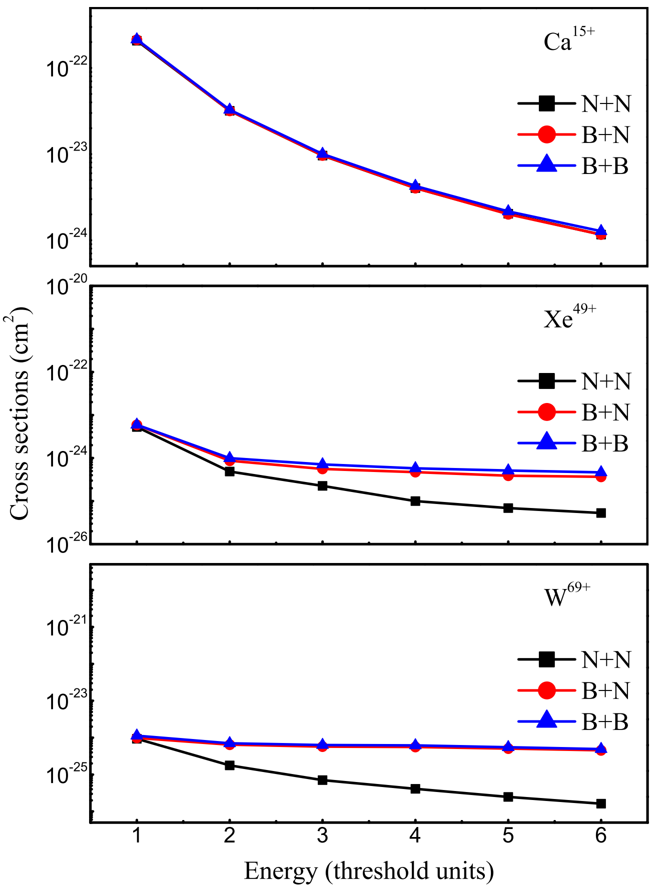

FIG. 3. The same as Fig. 1 but for the excitation to the excited state $[(1s2s^22p_{1/2})_02p_{3/2}]_{3/2}$.

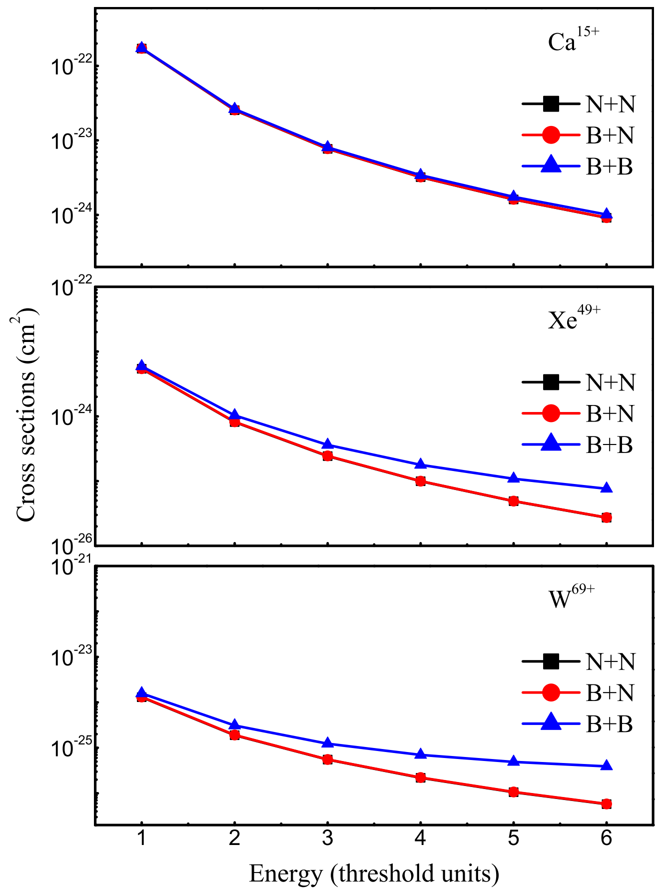

FIG. 4. The same as Fig. 1 but for the excitation to the excited state $[(1s2s^22p_{1/2})_12p_{3/2}]_{5/2}$.

momentum of the impact system (target ion plus free electron) and its z component; β represents all additional quantum numbers required to specify the initial and final states of the target ion in addition to the total angular momentum J and z component M; m_{s_i}, l_i, j_i, m_{l_i}, and m_i are the spin, orbital angular momentum, total angular momentum, and its z component quantum numbers of the incident continuum electron e_i, respectively; δ_{κ_i} denotes the phase factor of the continuum electron; κ is the relativistic quantum number, which is related to the orbital and total angular momentum l and j; and k_i is the relativistic wave number of the incident electron,

$$k_i^2 = \varepsilon_i\left(1 + \frac{\alpha^2\varepsilon_i}{4}\right), \tag{8}$$

where α is the fine-structure constant. It turns out that $R(\gamma_i, \gamma_f)$ is independent of M and is expressed as

$$R(\gamma_i, \gamma_f) = \left\langle \Psi_{\gamma_f} \right| \sum_{p,q,p<q}^{N+1} (V_{\text{Coul}} + V_{\text{Breit}}) \left| \Psi_{\gamma_i} \right\rangle, \tag{9}$$

in which Ψ_{γ_i} and Ψ_{γ_f} represent the antisymmetric $(N+1)$-electron wave functions of the initial and final states of the impact systems, respectively, and V_{Coul} is the Coulomb operator and V_{Breit} denotes the Breit operator, which is given by [31]

$$V_{\text{Breit}} = -\frac{\alpha_p \cdot \alpha_q}{r_{pq}}\cos(\omega_{pq} r_{pq}) + (\alpha_p \cdot \nabla_p)(\alpha_q \cdot \nabla_q)\frac{\cos(\omega_{pq} r_{pq}) - 1}{\omega_{pq}^2 r_{pq}}, \tag{10}$$

where α_p and α_q are the Dirac matrices of the p and q electrons, respectively, and ω_{pq} is the angular frequency of the exchanged virtual photon.

When without detecting the scattered electron, the degree of linear polarization of the radiation lines emitted is defined experimentally as [32]

$$P = \frac{I_\parallel - I_\perp}{I_\parallel + I_\perp}, \tag{11}$$

where $I_\parallel$ and $I_\perp$ are the intensities of photons emitted with the electric vectors parallel and perpendicular to the direction of the incident electron beam, respectively. In theory, if we assume that EIE is the only mechanism for populating the relevant excited levels, the degree of linear polarization of the corresponding emission lines can be calculated with the use of the expressions [27]

$$P(J = 3/2) = \frac{3\alpha_2(\sigma_{1/2} - \sigma_{3/2})}{1 + \alpha_2(\sigma_{1/2} - \sigma_{3/2})}, \tag{12}$$

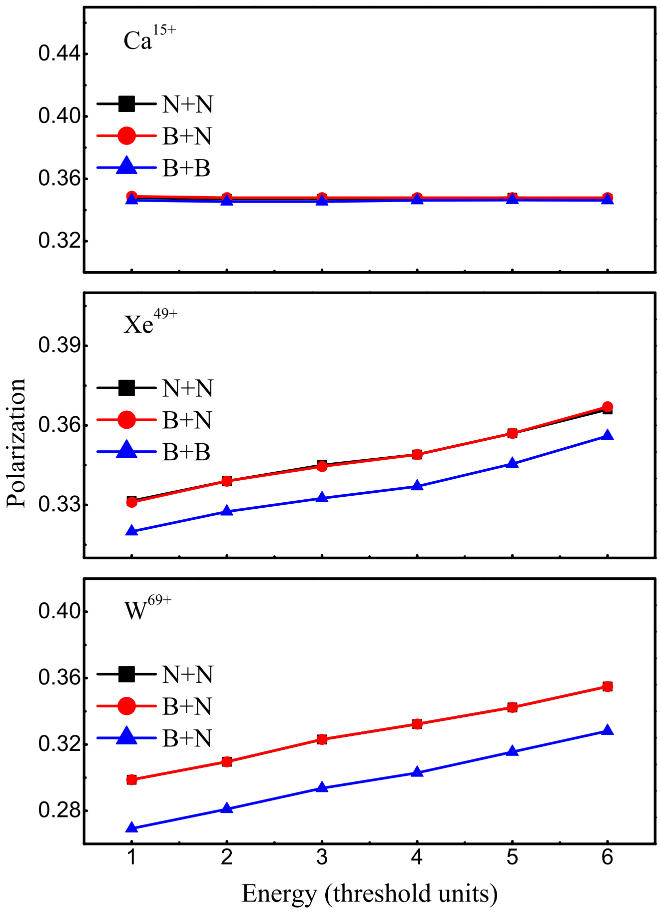

FIG. 5. Degrees of linear polarization of the emission line radiated from the $[(1s^22s2p_{1/2})_02p_{3/2}]_{3/2} \rightarrow 1s^22s^22p_{1/2}$ transition of highly charged boronlike Ca^{15+}, Xe^{49+}, and W^{69+} ions as functions of incident electron energy in threshold units.

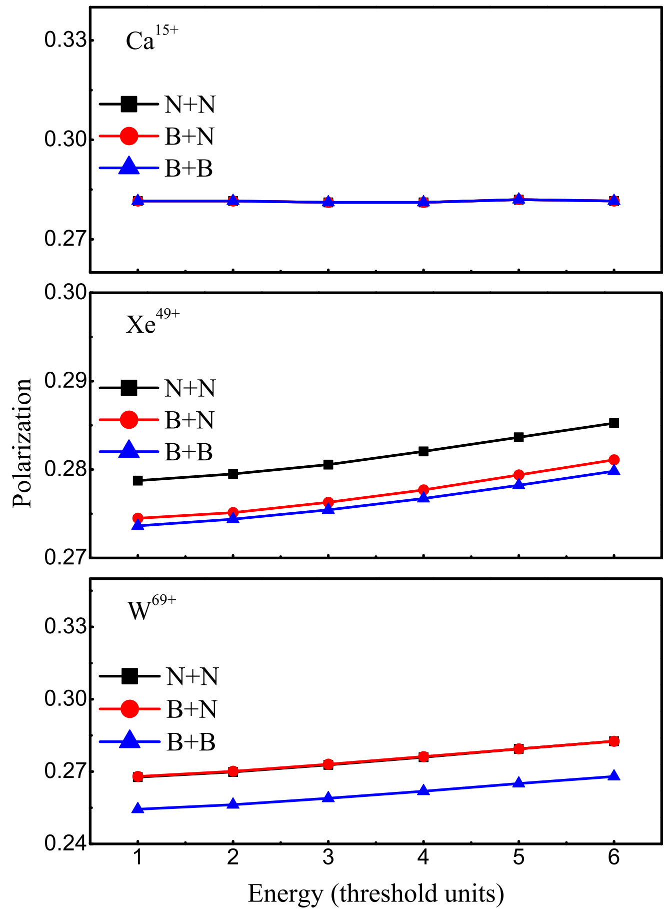

FIG. 6. The same as Fig. 5 but the emission line radiated from the $[(1s^22s2p_{1/2})_12p_{3/2}]_{5/2} \rightarrow 1s^22s^22p_{3/2}$ transition.

$$P(J=5/2) = \frac{3\alpha_2(4\sigma_{1/2}+\sigma_{3/2}-5\sigma_{5/2})}{\sqrt{14}+(4\sigma_{1/2}+\sigma_{3/2}-5\sigma_{5/2})}, \quad (13)$$

where J is total angular momentum of the excited state, and $\sigma_{1/2}$, $\sigma_{3/2}$, and $\sigma_{5/2}$ denote the EIE cross sections for the excitations from the ground state to the magnetic sublevels $m_f = 1/2, m_f = 3/2$, and $m_f = 5/2$ of the respective excited states, respectively. Moreover, the coefficient α_2 was defined as [27]

$$\alpha_2 = (-1)^{J+J_f-1}\sqrt{\frac{3(2J+1)}{2}}\begin{Bmatrix} 1 & 1 & 2 \\ J & J & J_f \end{Bmatrix}, \quad (14)$$

in which J and J_f denote total angular momenta of the initial and final states of a specific EIE process, respectively, and a standard notation has been utilized for the Wigner-$6j$ symbol.

III. RESULTS AND DISCUSSION

In the calculations of wave functions and energy levels of the relevant initial and final states, we have used three correlation models that are labeled by A, B, and C. In model A, the configurations $1s^22s^22p$, $1s^22s2p^2$, and $1s2s^22p^2$ are considered, which have 18 configuration state functions (CSFs). Model B includes both the ones in model A and the $1s^22s^23l$, $1s^22s2p3l$, and $1s2s^22p3l (l = s, p, d)$ configurations (119 CSFs). Similarly, model C consists of the ones in model B as well as the $1s^22s^24l$, $1s^22s2p4l$, and $1s2s^22p4l (l = s, p, d, f)$ configurations (270 CSFs). Moreover, the correction of the QED effect has been also taken into account. In the following, we shall investigate in detail the four EIE processes as formulated by Eqs. (3)–(6).

In Table I the excitation energies calculated, respectively, with models A, B, and C for highly charged boronlike Ca^{15+}, Xe^{49+}, and W^{69+} ions are tabulated together with other available results [33] for comparisons. It can be found that the excitation energies given by models A and B show big discrepancies with the results in Ref. [33]. In contrast, the results given by model C are in reasonable agreement with the ones in Ref. [33]. From such a comparison, it becomes clear that model C can give rise to a relatively more accurate description for the corresponding target states of ions. Therefore, we are going to employ model C to calculate EIE strengths, cross sections, and linear polarization of the emission lines. Moreover, it is found that the Breit interaction makes the excitation energies decrease, and its contribution becomes more and more important with the increase of atomic number Z.

For further explaining the accuracy of the present results, the EIE collision strengths from the ground state

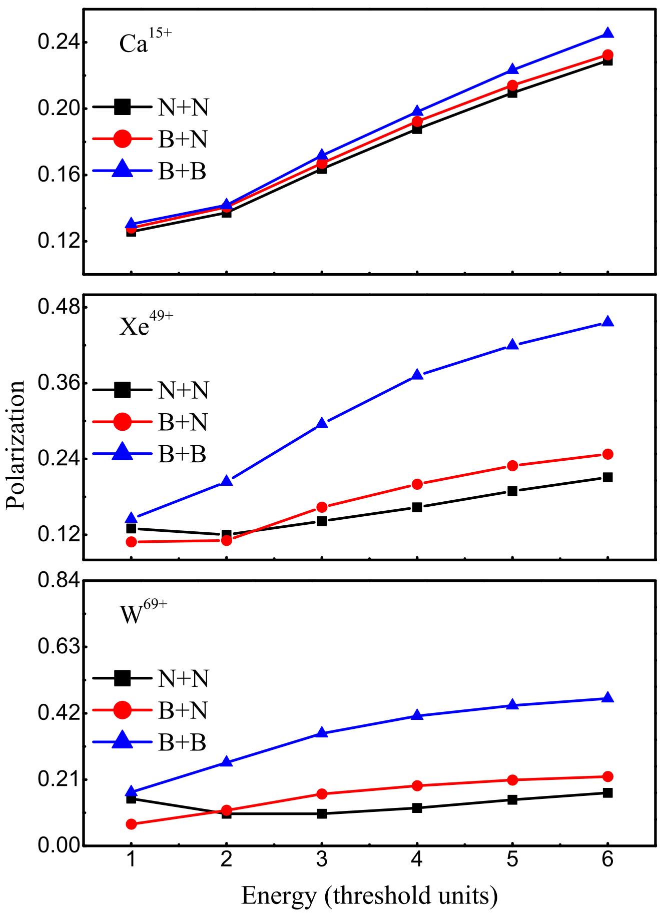

FIG. 7. The same as Fig. 5 but for the excitation to the excited state $[(1s2s^2 2p_{1/2})_0 2p_{3/2}]_{3/2}$.

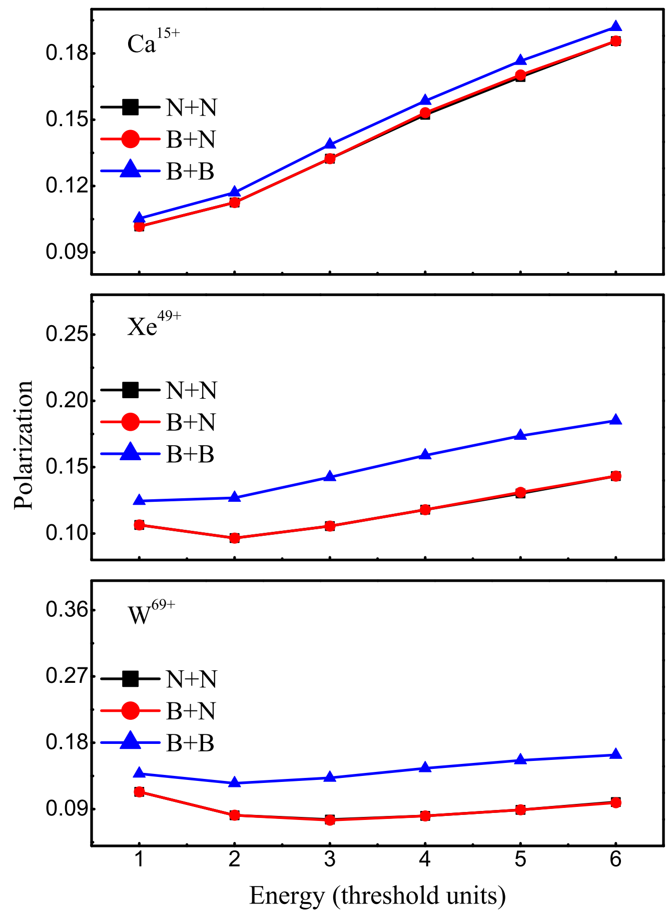

FIG. 8. The same as Fig. 5 but the emission line radiated from the $[(1s2s^2 2p_{1/2})_1 2p_{3/2}]_{5/2} \rightarrow 1s^2 2s^2 2p_{3/2}$ transition.

$1s^2 2s^2 2p_{1/2}$ to the excited states $[(1s^2 2s2p_{1/2})_0 2p_{3/2}]_{3/2}$ and $[(1s^2 2s2p_{1/2})_1 2p_{3/2}]_{5/2}$ of boronlike Ca^{15+}, Xe^{49+}, and W^{69+} ions at scattered electron energy $E' = 0.03$ in units of $(Z - 3.33)^2$Ry are listed in Table II together with other available results [33]. In order to discuss the effect of the Breit interaction on the EIE strengths clearly, three cases (i.e., N+N, B+N, and B+B) have been considered. N+N denotes that both the target wave functions and impact matrix elements are calculated without the Breit interaction included; B+N denotes the former are calculated with an inclusion of the Breit interaction but the latter without the Breit interaction included; and B+B represents both of them are calculated with the Breit interaction included. It is found that the present EIE strengths are in very good agreement with the results in Ref. [33]. Moreover, we also find the Breit interaction contributes positively the EIE strengths, although this kind of contribution is relatively small.

Figures 1 and 2 display total EIE cross sections for the excitations from $2s$ to $2p$ of highly charged boronlike Ca^{15+}, Xe^{49+}, and W^{69+} ions. It is found that the cross sections decrease in the same pattern with increasing incident electron energy for all of the situations. Moreover, we also find that the Breit interaction makes very weak contributions to the total EIE cross sections, however, which is very different from the case of the excitations from $1s$ to $2p$ of the same boronlike ions. In the latter case, the Breit interaction plays a dominant role in the calculations of the impact matrix elements and thus contributes significantly to the corresponding total EIE cross sections, especially for the ions with big atomic number at high incident electron energies, as shown in Figs. 3 and 4. Finally, it is necessary to state that we also calculated the magnetic sublevel cross sections for the EIE processes as formulated by Eqs. (3)–(6), although they are not presented in this contribution for the sake of brevity.

With the EIE magnetic sublevel cross sections ready, they can be further employed to calculate the degrees of linear polarization of the corresponding emission lines by using Eqs. (12)–(13). In Figs. 5–8 we plotted the degrees of linear polarization of the transition lines [i.e., the second step of Eqs. (3)–(6), respectively] of boronlike Ca^{15+}, Xe^{49+}, and W^{69+} ions as functions of incident electron energy. Compared to the EIE strengths and total cross sections, the degrees of linear polarization are found much more sensitive to the Breit interaction. This is because the linear polarization depends on relative populations of the magnetic sublevels instead of the total cross sections. As seen clearly from the figures, the effect of the Breit interaction on the wave functions of target ions hardly influencee the degrees of linear polarization in all of the situations. That is to say, the contribution of the Breit interaction to the degrees of linear polarization comes dominantly from the effect of the Breit interaction on the EIE matrix elements. Moreover, the Breit interaction makes the emission lines following the excitations from $2s$ to $2p$ depolarized (see Figs. 5–6), while it makes the ones following the excitations from $1s$ to $2p$ more polarized as seen from Figs. 7–8. Obviously, the difference in the results of the degrees of linear polarization is due to only the interplay of different numerical contributions. This is because the degrees of linear polarization of x-ray lines are determined by the (relative) magnetic sublevel cross sections, as can be seen from Eqs. (12) and (13). The contribution of the Breit interaction to the relative population of the magnetic sublevels in the $2s \to 2p$ and $1s \to 2p$ excitations is different, which is eventually reflected in the degrees of linear polarization of the $2p \to 2s$ and $2p \to 1s$ emission lines. These conclusions are very different from the results obtained for the linear polarization of the same emission lines but formed via the dielectronic recombination process, in which the Breit interaction has no effect on the linear polarization [27]. Admittedly, such a difference is caused by different population mechanisms of the excited states, as well discussed in Ref. [34]. Similarly to the cases of the strengths and total cross sections, it is found that the effect of the Breit interaction on the linear polarization becomes more and more evident with increasing incident electron energy and atomic number. To end, we would like to mention that the presently obtained degrees of linear polarization are experimentally measurable with present-day x-ray spectrometers or polarimeters [25,35,36].

IV. CONCLUSION

In summary, electron-impact excitation cross sections from the ground state $1s^2 2s^2 2p_{1/2}$ to the excited states $[(1s^2 2s 2p_{1/2})_0 2p_{3/2}]_{3/2}$, $[(1s^2 2s 2p_{3/2})_1 2p_{3/2}]_{5/2}$, $[(1s 2s^2 2p_{1/2})_0 2p_{3/2}]_{3/2}$, and $[(1s 2s^2 2p_{3/2})_1 2p_{3/2}]_{5/2}$ of highly charged boronlike Ca^{15+}, Xe^{49+}, and W^{69+} ions have been calculated by using a fully relativistic distorted-wave method. These cross sections are further employed in calculating the degrees of linear polarization of the corresponding x-ray emissions. We have analyzed the influence of the Breit interaction on the cross sections and the degrees of linear polarization. At given incident electron energies, it is found that the Breit interaction makes the electron-impact excitation cross sections increase, and such an effect on the cross sections of the $1s \to 2p$ excitation is much larger than the ones of the $2s \to 2p$ excitation. As for the degrees of linear polarization, it is found that the Breit interaction makes the lines corresponding to the $2p \to 2s$ transition depolarized, while it makes the lines corresponding to the $2p \to 1s$ transition more polarized. Moreover, this kind of influence becomes more evident for higher incident electron energies and atomic number. These characteristics are very different from the results obtained for the linear polarization of the same emission lines but formed via the dielectronic recombination process, in which the Breit interaction has no effect on the linear polarization [27].

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