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Depolarization of the resonance line of $C4^+$ due to the electron beam density effect

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Abstract: We investigate theoretically the linear polarization of the Helium-like resonance line 1s2p 1P1 1s2 1S0 emitted from C4+ ions using a steady-state collisional-radiative model, taking into account both the excitation from the ground level 1s2 1S0 and the metastable level 1s2s 1S0 in the population of the 1s2p 1P1 upper level of the resonance line. We analyze the behavior of the linear polarization of the resonance line with respect to the electron density in a wide range varying from 1011 to 1017 cm-3 and for three specific energies of the electron beam. Our results show that when the electron density is sufficiently high, the excitation 1s2s 1S0 1s2p 1P1 provide a significant contribution to the population rate of 1s2p 1P1 level which lead to an important depolarization of the resonance line.

Keywords: Linear Polarization Degree; Resonance Line; Collisional-Radiative Model; Helium-Like Ions; Electron-Ion Collisions

1. Introduction

Plasma spectroscopy is one of the disciplines of plasma physics, and it has played an important contributing role to the development of plasma physics through plasma diagnostics by providing important information on electron density and temperature, and on transport of plasma particles in a plasma.

Plasma spectroscopy is characterized by its strong relationship to, or basis of, atomic physics. This is because the object which emits spectral lines are atoms

or ions, and their behavior in a plasma is controlled by a collection of processes that are the realm of atomic physics. Plasma Polarization Spectroscopy (PPS) is a branch of plasma spectroscopy, which provides information on electric and magnetic fields and electron distribution functions. The strong relationship with atomic physics is even more true for PPS.

During the last 40 years, plasma polarization spectroscopy attracted considerable attention. It has been stimulated by the development of sophisticated experimental techniques which performed spectropolarimetric observations of laboratory and celestial plasma, and by the substantial progress of theoretical and experimental investigations on the cross sections [1]. Solar atmosphere was an important target of PPS, solar flares, in which anisotropic excitation of ions by electrons having a directional motion would produce alignment, were subject of PPS observations [2]. In laboratories, vacuum spark, and plasma focuses were also the target of PPS observations [3]. The z-pinch, and the so-called X-pinch were investigated vigorously [4], [5]. Many experiments of x-ray polarization spectroscopy have been performed [6]. Helium-like resonance line emissions from various He-like ions, such as F [7], Cl [8], [9] C and Cu [10] have been measured. To the best of our knowledge, until now, the theory used to study the polarization is the simple atomic model of Kieffer et al. [11] which has been repeatedly criticized [1], [12].

The aim of the present paper is to study theoretically the linear polarization of the resonance line emitted from Carbone Helium like ions using a steady-state collisional-radiative model, taking into account both the excitation from the ground level 1s2 1S0 and the metastable level 1s2s 1S0 in the population of the 1s2p 1P1 upper level of the resonance line. We analyze the behavior of the linear polarization of the resonance line with respect to the electron density in a wide range varying from 1011 to 1017 cm-3 and for three specific energies of the electron beam.

2. Basic Formula - Atomic Data

Line radiation emitted from ions collisionally excited by electrons with a velocity distribution that is axially symmetric with respect to some z axis is, in general, linearly polarized. The polarization degree of the resonance w line can be written as :

$$P(w) = (N_0 - N_1) / (N_0 + N_1) \qquad (1)$$

where N_{Mj} denote the population of the upper magnetic sub-level $M_j = 0, 1$ of the 1s2p $^1P_1$ 1s^2 $^1S_0$ line which is determined in a steady-state collisional- radiative model. The population N_{Mj} is solution of a coupled set of rate equation, the one which explicitly govern it can be written as :

$$N_{Mj} A_w = N(1^1S_0)\, n_e\, C(1^1S_0\ 2^1P_1, M_J) +$$
$$+ N(2^1S_0)\, n_e\, C(2^1S_0\ 2^1P_1, M_J) \qquad (2)$$

Where A_w denote the radiative probability transition from 2^1P_1 to the ground level. $C(1^1S_0\ 2^1P_1, M_J)$ and $C(2^1S_0\ 2^1P_1, M_J)$ are, respectively, the collisional rate coefficients of the excitation of the $2^1P_1, M_J$ magnetic sublevels from the ground and the metastable levels. n_e is the electron beam density, $N(1^1S_0)$ and $N(2^1S_0)$ are, respectively, the population of the ground and the metastable levels.

$$N(2^1S_0) = [N(1^1S_0)\, n_e\, C(1^1S_0\ 2^1S_0)]$$
$$[A(2^1S_0\ 1^1S_0) + n_e\, C(2^1S_0\ 2^1P_1)] \qquad (3)$$

$C(1^1S_0\ \ 2^1S_0)$ is the rate coefficient of the collisional excitation of the metastable level from the ground level. $A(2^1S_0\ 1^1S_0)$ is two photon radiative probability transition from 1s2s $^1S_0$ to 1s^2 $^1S_0$. The equation governing the population of the magnetic sub-levels M_J of the 2^1P_1 level becomes:

$$N_{MJ} = \{N(1^1S_0)\, n_e / A(2^1P_1\ .\ 1^1S)\} \times \{C(1^1S_0\ .\ ^1P_1, M_J)$$
$$+ [n_e C(1^1S_0\ ^1P_1, M_J) C(1^1S_0\ .\ ^1S\ .\ ^1S_0\ .\ 1^1S_0) +$$
$$+\ ne\ C(2^1S_0\ \ 2^1P_1] \} \qquad (4)$$

The rate coefficient C for the electron beam, in cm^3 s^{-1}, is obtained from the relationship

$$C(\Delta_i J_i M_i \Delta_j J_j M_j) = 7.099 \times 10{-}8 \times$$
$$\Omega(\Delta_i J_i M_i \Delta_j J_j M_j) / e_0^{1/2} \qquad (5)$$

where the kinetic energy of the electron beam e_0 is taken in eV and where $\Omega(\Delta_i J_i M_i \Delta_j J_j M_j)$ is the collision strength for incident electrons along z axis. The explicitly expressions of the rate coefficients C is given in [13].

The required atomic data for the calculation of the linear polarization of the resonance line were computed using the flexible atomic code FAC.

In table 1 we display the collision strengths for C^{4+} for three energies e_0= 310, 486 and 1500 eV.

Table 1. *Collision strengths for He-like C 4+ for three energies e0= 310, 486 and 1500 eV for transitions from the ground level 11S0 and the metastable level 21S0 to 1s2p1P1, MJ magnetic sub-levels, and for the excitation from the ground level to the metastable level. Values for the threshold excitation energies E are also given. Note x[y] = x×10y.*

Transitions	**E**	**e0 (eV)**		
		310	486	1500
11S0→21P1	307.71	0.105	0.133	0.235
11S0→21P1 1		1.982[-2]	1.982[-2]	6.435[-2]
11S0→21P1 0		6.554[-2]	7.793[-2]	1.063[-1]
11S0→21S0	303.91	2.014[-2]	2.156[-2]	2.467[-2]
1S0→21P1	3.799	10.255	11.002	12.704
21S0→21P1 1		4.394	4.775	5.646
21S0→21P1 0		1.476	1.451	1.412

3. Results and Discussion

In Fig. 1 we display the polarization degree of the resonance line versus the electron beam density ranging from 1011 to 1017 cm-3 calculated for C4+ for three energies e0 = 310, 486 and 1500 eV, while in Fig. 2 we display the contribution of the excitation 1s2 1S0 1s2p 1P1 in the population of the upper level of the resonance line versus the electron beam density calculated for C4+ for the same energies.

Our results show a clearly depolarization of the resonance line due to the inclusion of the excitation from the metastable level 1s2s 1S0 to the population of the 1s2p 1P1, MJ magnetic sub-levels.

For an incident electron energy, 310 eV, just above the threshold 1s2 1S0 1s2p 1P1 we can see a significant contribution of the 1s2s 1S0 in the population of of the 1s2p 1P1 varying from 1% to 16% as the electron density increase from 1011 to 1015 cm-3 . This contribution induce a rapid depolarization of the resonance line from 54% to 43%.

In fact, when the electron density is sufficiently high, the transition 1s2s 1S0 . ls2p 1P1 induced by collisions competes with the two-photon electric-dipole decay 1s2s 1S0 . 1s2 1S0 and provide a significant contribution to the population rate of the ls2p 1P1 level.

At higher densities, where an almost full transfer of population from 1s2s 1S0 . ls2p 1P1 takes place by collisions, the polarization degree of the resonance line tends to 18% (e0=1500 eV).

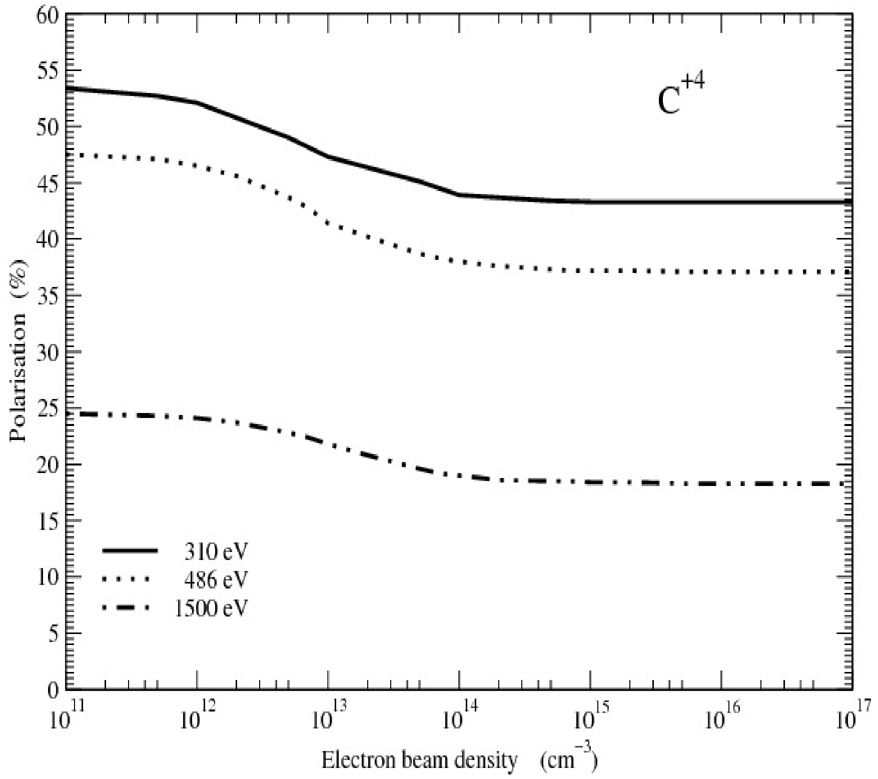

Figure 1. *Linear polarization degree for the resonance line versus the electron beam density calculated for C+4 for three energies e0 = 310, 486 and 1500 eV.*

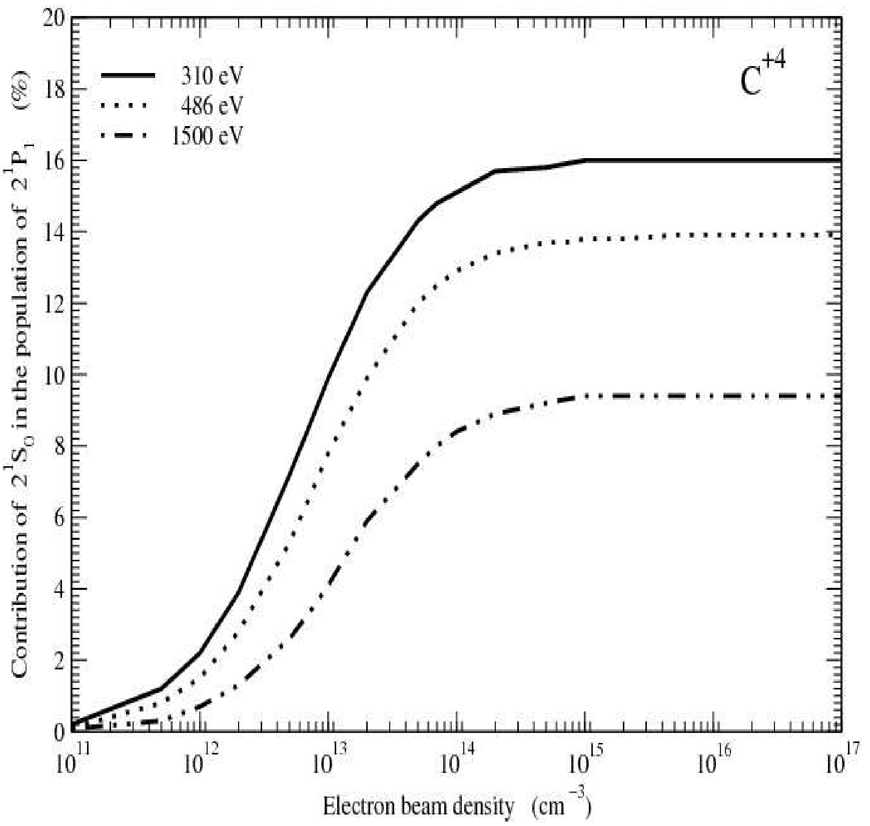

Figure 2. *Contribution of the excitation 1s2s 1S0 → 1s2p 1P1 in the population of the upper level of the resonance line versus the electron beam density calculated for C+4 for the enrgies e0 = 310, 486 and 1500 eV.*

5. Conclusion

In this wok we have reported calculations on the depolarization of the resonance line 1s2p 1P1 . 1s2 1S0 emitted by C4+ ions due to the inclusion of the contribution of the excitation 1s2s 1S0 . ıs2p 1P1 to the population rate of the ıs2p 1P1 level, for various incident electron energies in the range 310-1500 eV and for electron densities ranging from 1011 to 1017 cm-3.

We have shown that when the electron density is sufficiently high, the transition 1s2s 1S0 . ıs2p 1P1 induced by collisions competes with the two-photon electric-dipole decay 1s2s 1S0 . 1s2 1S0 and provide a significant contribution to the population rate of the ıs2p 1P1 level.

Such density effect lead to an important depolarization of the resonance line. This effect cannot be neglected and hence the simple coronal model used until now to study the characteristic of the polarization of the resonance line remain a very rough approximation.

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