Ionic Collision Broadening with in Impact Approximation in Semiclassical Plasma

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Abstract

The line shape responds to the various interactions between the emetter and the disruptors that preceded or accompanied the emission, by broadening and/or displacement. The average value of the electronic effect is often replaced by an electronic collision operator. In this thesis, we calculate the ionic collision operator for isolted lines by neglecting the fine structure. The path of the perturber ion is taken a hyperbole whose diffusion center is the emitting ion. The average effect of these collisions is calculated at impact parameters and initial speeds according to the Maxwell (non-relativist) velocity distributions. We then consider the movement of the disruptive ion around the emitting ion. We obtained, the ion collision operator as part of the impact approximation. A set of comparisons between the electronic collision operator and the ion operator was made for different values, electronic density, spectroscopic number, and temperature.

Keywords: ion collision operator, ion bradening, impact approximation.

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1-Introduction:

Plasma spectroscopy is the study of radiation emitted by a partially or completely ionized plasma. The information contained in the spectrum depends on the physics of the emitter ion and depends on the physics of the surrounding plasma [1,2,3,4]. This dependence is a direct consequence of the interaction of the charged particles forming the plasma with the emitter. The spectrum of the lines then responds to the multiple microscopic interactions which accompanied or preceded the emission by a broadening and/or a displacement [5,6,7,8,9]. The profile of the spectral lines is a very relevant representation of the emitter (ion) and its environment. Which is an analytical image of radiation reflecting microscopic reactions associated with exposure to emissions or movement [10,11,12,13].

The lines obtained in plasma spectroscopy are not infinitely finite and they have a profile which gives the distribution of the intensity in the line. The Stark effect is a mechanism for broadening the spectral line [14,15,16]. It occurs when an atom, a molecule, or an ion, which emits light in a gas, is disrupted by its interactions with the other constituents of the plasma gas, such as than other atoms, molecules, ions, or electrons. The study of this phenomenon is necessary for precise spectroscopic observations, it can also provide useful indications and information on the conditions and concentrations in the plasma [17]. Line broadening has become an important means of measuring temperatures across the full range of densities of plasma gas-forming species.

In a plasma, numerous works have been carried out to calculate the broadening of lines isolated from a plasma, using the impact approximation for electrons in its semi-classical version, and the quasi-static approximation for ions. In this work this will be the first time that we consider fast, mobile ions in hot plasma, so we will treat their contribution on broadening in the framework of the impact approximation. We have replaced the effect of ionic disruptors on the linewidth with an average value as an ion collision operator.We have maked comparisons between the electron collision operator and the ion collision operator in terms of (the temperature T, the electron density Ne and the charge spectroscopy number Z of the radiating ion. Next, we have drawed the profiles for different conditions.

2- Ionic collision operator:

The emitting ion in a plasma is influenced by the electric field due to electrons and ions. Electrons, fast particles, have very low masses and very short collision times compared to the time of interest. So they are treated by the impact approximation. The high velocities of the disruptors and the low densities are the conditions that must be achieved in order to apply the impact approximation in the cases of electron-ion interaction. For elastic ion-electron collisions, the semi-classical is mostly used theory[13]. In our suggestion, we considered that the ionic perturber have a high velocity in the case of hot plasmas. Therefore, we can treat the ionic perturber with the impact approximation. Then, we used the Alexiou approach to develop the ionic collision operator for a isolated line[12].

The effect of the ionic component on the broadening, in the impact approximation, can be defined as folloing average:

$$\phi(0) = -\frac{\pi N_e (z-1)^2 e^2}{\hbar^2} \int_0^\infty v f(v) dv \int_{\rho_{min}}^{\rho_{max}} \rho d\rho \int_{-\infty}^{\infty} dt_1 \int_{-\infty}^{\infty} dt_2 \, \vec{E}\,(t_1)\, \vec{E}\,(t_2)$$

The notations and represent the integration limits on the impact parameter which written as:

$$\rho_{max} = \lambda_D$$

$$\rho_{min} \approx \sqrt{\frac{2}{3}} \frac{\hbar\left(n_e^2 - n_g^2\right)}{m(Z+1)v}$$

Second, neglecting the fine structure of the emitting ion, is the electric field created by the disturbing ion, defined as:

$$\vec{E}(t_1).\vec{E}(t_2) = K^2(Z-1)^2e^2\frac{X_1X_2 + Y_1Y_2}{(r_1)^3(r_2)^3}$$

In the case of an ion emitter, the trajectory is a hyperbola of eccentricity and semi-major axis .

$$X = r\cos\varphi = \rho_0(\varepsilon + \cosh x)$$

$$Y = r\sin\varphi = \rho_0\sqrt{\varepsilon^2 - 1}\,\sinh x$$

Where

$$\varepsilon = \sqrt{1 + \left(\frac{\rho}{\rho_0}\right)^2}$$

$$\rho_0 = \frac{\alpha}{mv} = \frac{(Z-1)^2e^2}{4\pi\varepsilon_0 mv^2}$$

Using the parametric equations (X), (Y), (r), the ionic collision operator for isolated lines is written as:

$$\phi_i = -\frac{\pi N_i(z-1)^2e^4}{3\hbar^2}\left(\frac{1}{4\pi\epsilon_0}\right)^2 \int_0^{\infty} \frac{f(v)}{v}dv \int_{\rho_{min}}^{\rho_{max}} \frac{\rho}{\rho_0^2}d\rho \int_{-\infty}^{\infty} dx_1 \int_{-\infty}^{\infty} dx_2$$
$$\times \frac{(\varepsilon + \cosh x_1)(\varepsilon + \cosh x_2) + (\varepsilon^2 - 1)\sinh x_1 \sinh x_2}{(\varepsilon\cosh x_1 + 1)^2(\varepsilon\cosh x_2 + 1)^2}$$

We change the variable then the integration over passes to the integration over ,

$$\frac{\rho}{\rho_0^2}d\rho = \varepsilon d\varepsilon$$

$$\phi(0) = -\frac{\pi N_i(z-1)^2e^4}{3\hbar^2}\frac{1}{(4\pi\varepsilon_0)^2}\sqrt{\frac{2}{\pi}}\left(\frac{m}{K_BT}\right)^{3/2}\int_0^\infty v\exp(-\frac{mv^2}{2K_BT})dv\int_{\varepsilon_{min}(v)}^{\varepsilon_{max}(v)}\frac{d\varepsilon}{\varepsilon}\left[G_1(\varepsilon)G_1(\varepsilon)+\frac{\varepsilon^2-1}{\varepsilon^2}G_2(\varepsilon)G_2(\varepsilon)\right]$$

$$\phi(0) = -\frac{\pi N_i(z-1)^2e^4}{3\hbar^2}\frac{1}{(4\pi\varepsilon_0)^2}\sqrt{\frac{2}{\pi}}\left(\frac{m}{K_BT}\right)^{3/2}\int_0^\infty v\exp(-\frac{mv^2}{2K_BT})dv\int_{\varepsilon_{min}(v)}^{\varepsilon_{max}(v)}\frac{d\varepsilon}{\varepsilon}\left[G_1^2(\varepsilon)+\frac{\varepsilon^2-1}{\varepsilon^2}G_2^2(\varepsilon)\right]$$

From the equation that related the impact parameter and the eccentricity we can deduce :

$$\varepsilon_{min} = \sqrt{1+\left(\frac{\rho_{min}}{\rho_0}\right)^2}$$

$$\varepsilon_{max} = \sqrt{1+\left(\frac{\rho_{max}}{\rho_0}\right)^2}$$

where ε_{max} , and ε_{min} are the integration bounds on the impact parameter.

The functions in formula the formula of G are:

$$G_1(\varepsilon) = \int_{-\infty}^{\infty} dx\frac{\left(1+\frac{\cosh x}{\varepsilon}\right)}{(\cosh x+\frac{1}{\varepsilon})^2}$$

$$G_2(\varepsilon) = \int_{-\infty}^{\infty} dx\frac{\sinh x}{(\cosh x+\frac{1}{\varepsilon})^2}$$

Neglecting the fine structure of the emitter ion $\omega = 0$, we find

$$G_1(\varepsilon) = \int_{-\infty}^{\infty} dx\frac{\left(1+\frac{\cosh x}{\varepsilon}\right)}{(\cosh x+\frac{1}{\varepsilon})^2} = \left[\frac{2\varepsilon(\varepsilon^2-1)\tanh(\frac{x}{2})}{(\varepsilon^2-1)\left[(\varepsilon+1)\tanh(\frac{x}{2})^2+\varepsilon-1\right]}\right]_{-\infty}^{\infty} = \frac{2\varepsilon(\varepsilon^2-1)}{2\varepsilon(\varepsilon^2-1)} - \frac{2\varepsilon(\varepsilon^2-1)(-1)}{2\varepsilon(\varepsilon^2-1)} = 2$$

$$G_2(\varepsilon) = \int_{-\infty}^{\infty} \frac{dx\sinh x}{(\cosh x+\frac{1}{\varepsilon})^2} = 0$$

By injecting the functions $G_1(\varepsilon)$ and $G_2(\varepsilon)$ into the G expression, we obtain:

$$\phi = -\frac{4\pi N_i(z-1)^2 e^4}{3\hbar^2}\frac{1}{(4\pi\varepsilon_0)^2}\sqrt{\frac{2}{\pi}}\left(\frac{m}{K_B T}\right)^{3/2}\int_0^{\infty} v\exp\left(-\frac{mv^2}{2K_B T}\right)dv\int_{\varepsilon_{min}(v)}^{\varepsilon_{max}(v)}\frac{d\varepsilon}{\varepsilon}$$

By integrating over the eccentricity , we arrive at the formula for the direct term of the electronic collision operator :

$$\phi = -\frac{4\pi N_i(z-1)^2 e^4}{3\hbar^2}\frac{1}{(4\pi\varepsilon_0)^2}\sqrt{\frac{2}{\pi}}\left(\frac{m}{K_B T}\right)^{3/2}\int_0^{\infty} v\exp\left(-\frac{mv^2}{2K_B T}\right)dv\,\ln\frac{\varepsilon_{max}}{\varepsilon_{min}}$$

This last expression present ionic collision operator for elastic ion-ion collisions using the impact theory.

3-Results and discussions

Previous studies have calculated the influence of the effect of ion collisions on Stark broadening, where these collisions were estimated within the framework of the quasi-static approximation. In this work, we will make comparisons between the ionic collision operator ϕ and the electronic collision operator ϕ_e .

in terms of the temperature T , electron density N_ea and charge spectroscopy number Z of the emitting ion Sc^{+20} . Next, we estimate the influence of our correction on the Stark broadening.

We maked comparisons between the ion collision operator ϕ_e. and the electron collision operator The comparison can be made in the case where the fine structure of the emitting ion is neglected. We note the percentage $P(\%)$ of our correction on the operator:

$$P = \frac{\phi - \phi_e}{\phi}\times 100$$

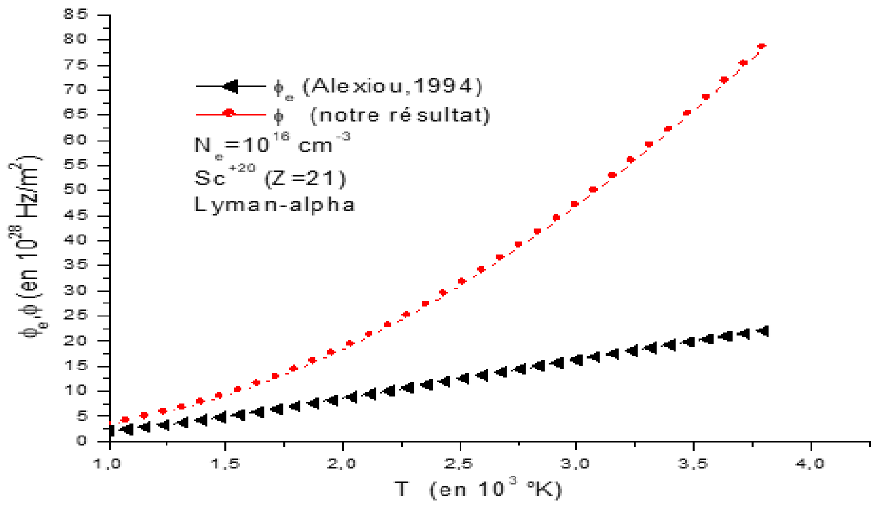
We discuss here how an increase in density reveals our correction on Stark broadening in an egenerated plasma Sc^{+20}.

Figure (3) shows the percentage change $P(\%)$ as a function as N_e for the Sc^{+20} to $T = 3\times10^9$ ^0K . We notice that the percentage decreases to reach a constant minimum value 35%.

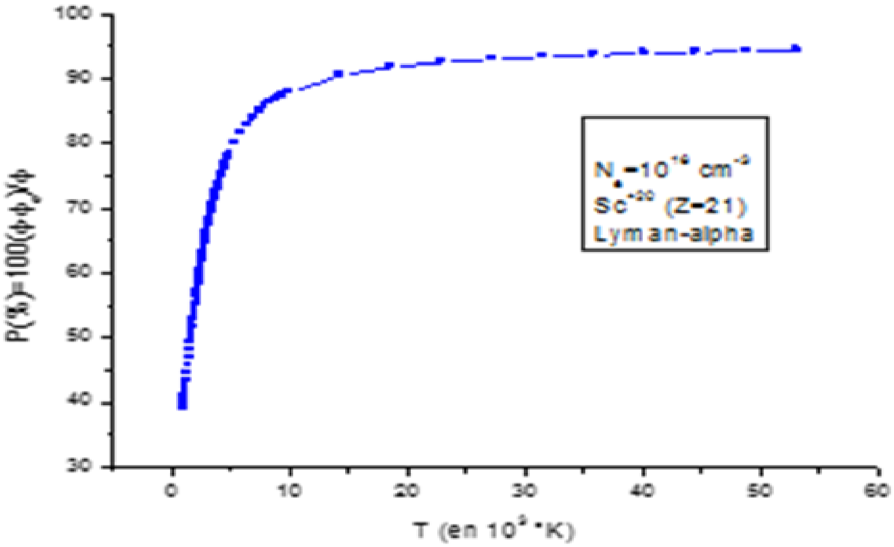
We present in figure (4), the variations of the operators $\underline{\ell}$ and $\underline{\Omega}_e$ depending on the spectroscopy number Z for $(N_e = 10^{16} cm^{-3}, T = 1.16 \quad 10^3 \quad {}^0K$. We notice that the two operators become have the same appearance. It appears that the two curves decrease exponentially to reach a constant value equal to a 0. Figure (5) shows the percentage change $P(\%)$ versus Z for $(N_e = 10^{16} cm^{-3}, T = 1.16 \quad 10^3 \quad {}^0K$ We notice that the percentage decreases with the number spectroscopy Z.

In figure (6), we present the effect of the ion collision operator ϕ and the electron collision operator ϕ_e on the $Ly-\alpha$ hydrogenoid Scandium line Sc^{+20} , for an electron density N_e of 10^{16}cm^{-3} , and an electron temperature $T = 1.8 \times 10^{3\circ}\text{K}$. We calculated the profile of the line $Ly-\alpha$. Taking into account the effect of the ionic collision operator on the width of the line, we notice that the line is less intense and wider compared to the line traced with the electronic collision operator.

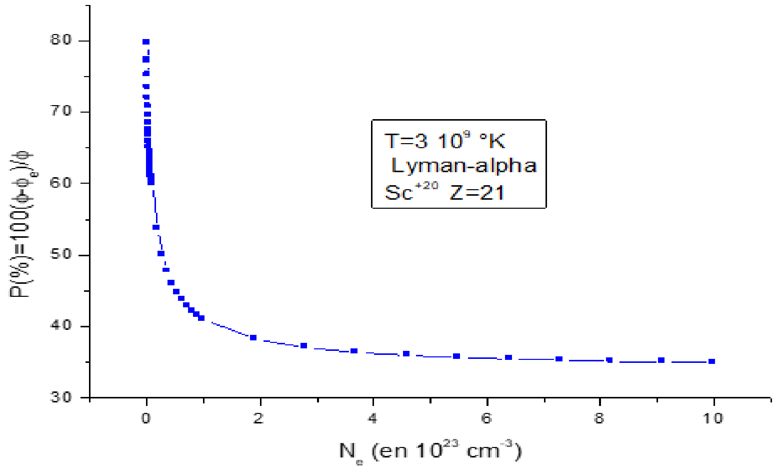
Figure (7) presents the effect of the ion collision operator ϕ_e and electron collision operator on the hydrogenoid Scandium line Sc^{+20}, at an electron density $N_e \; 10^{16} \; m^{-3}$, and at an electron temperature $T = 2.52 \times 10^3$. We notice that the effect of the ionic collision operator on the line width is less intense and wider compared to the line of the electronic collision operator.



Figures (1): variation of ionic and electronic operators as a function as T.



Figures (2): variation of percentage P operators as a function as T.



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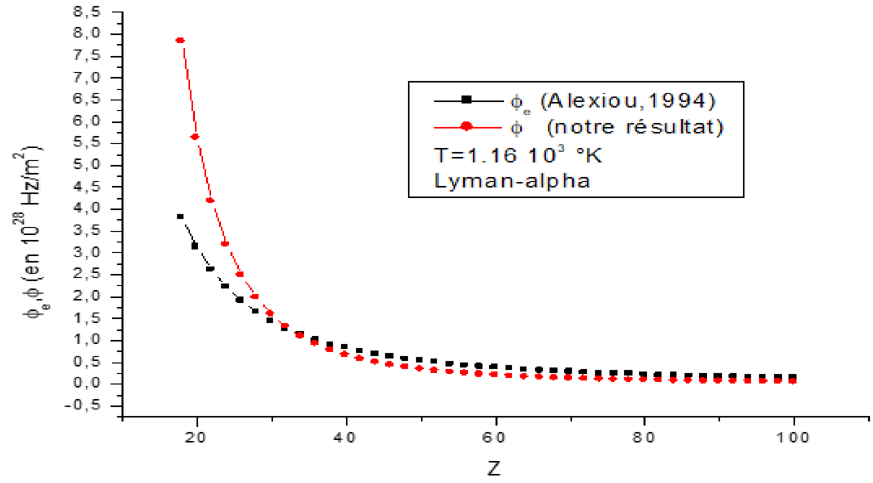
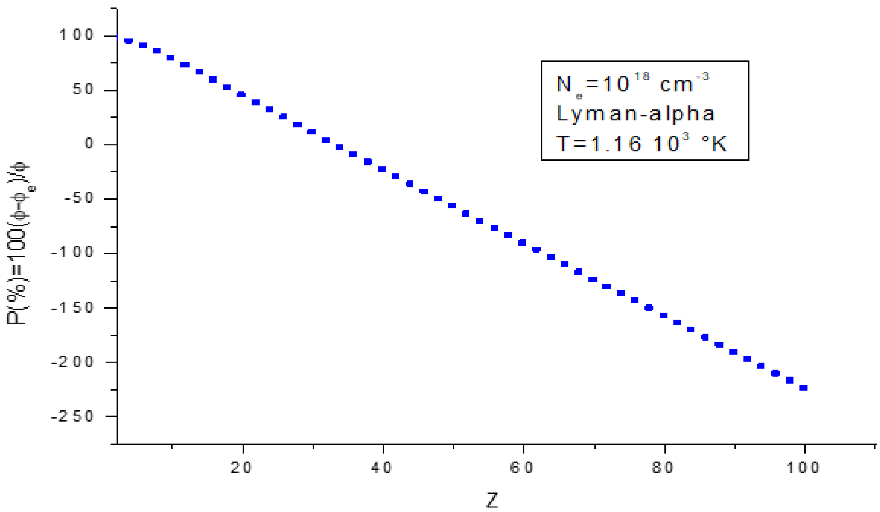
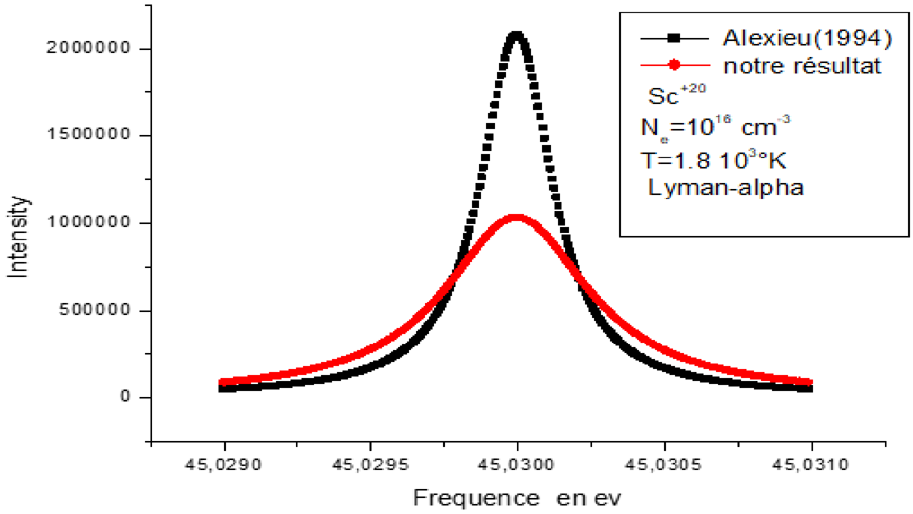
Figures (3): variation of percentage P operators as a function as Ne.



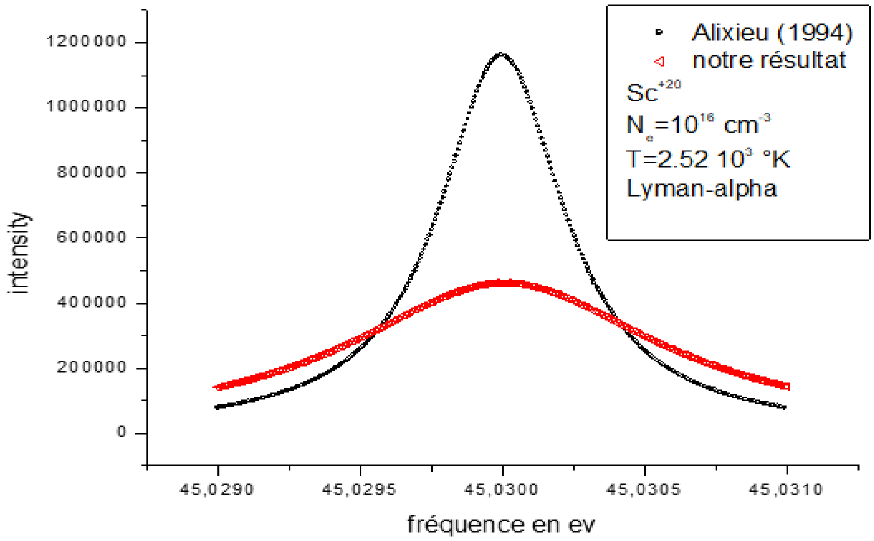
Figures (4): variation of ionic and electronic operators as a function as Z.



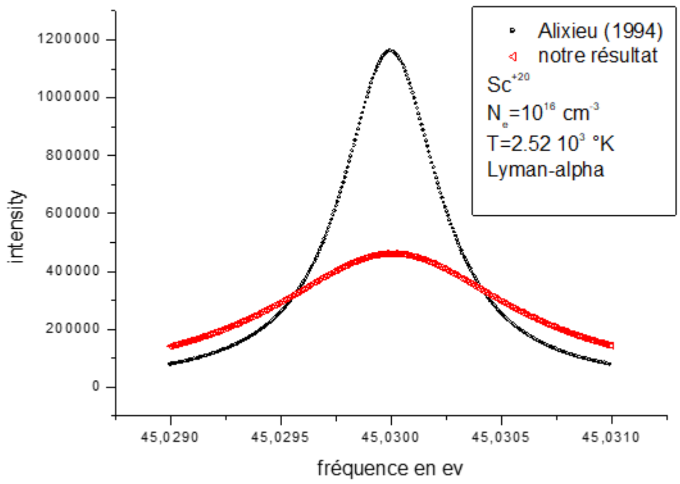
Figures (5): Behaviors of the percentage P(%) us a function Z.



Figures (6): The ionic ceffect correction on the line Ly-alpha.



Figures (7): The ionic ceffect correction on the line Ly-alpha.



Figures (7): The ionic ceffect correction on the line Ly-alpha.

4-Conclusion

Electrons are generally much faster since they have a much lower mass than ions. The emitting ion in a plasma is influenced by the electric field due to the disturbing ions, these ions are particles, heavy, and considered immobile. But in the hot plasma, the ions are considered fast, mobile, so we will treat their contribution to the broadening within the framework of the impact approximation. The contribution of the ionic disruptors in the broadening is presented by micro ionic fields .

In our case we we replaced the effect of the ionic disruptors on the linewidth by an average value like an ionic collision operator. We have find that the derived formula of ionic operator gives a good estimation of ionic contribution in the line brouadening.

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