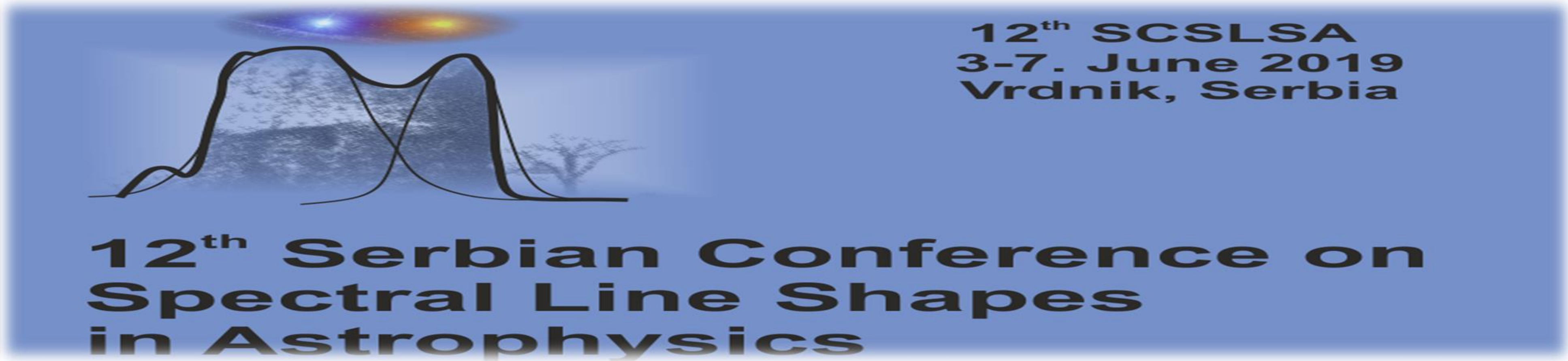


Collisional contribution to the Spectral line shape in magnetized plasmas

K. Touati (*), L. Houas (**) et M.T. Meftah (**)

(*) *L*P. les Alpilles, Rue des Lauriers, 13140 Miramas, France.
(**), Département de physique, LRPPS, Université de Ouargla 30000, Algérie

INTRODUCTION

* *The collisional contribution to the spectral line shape is modified by the presence of the magnetic field, in the case of electronics perturbers, the resolution of the stochastic equation is based on the theory of impact of the interaction [M. Baranger].*

** *In the standard model, the emitter is subjected to a succession of independent collisions carried out by the electrons,*

*** *The effect of electrons perturbers is presented by a phenomenological operator of electronic collisions [H. Huddlestone et al], which can be calculated by the relaxation method [Griem et al],*

**** *This collision operator $\Phi(\vec{v}, \vec{B})$ must take into account the influence of the magnetic field on the collision : the trajectory of the perturbers is modified in the presence of the magnetic field, as well as the velocity distribution function.*

12th SCSLSA
3-7. June 2019
Vrdnik, Serbia

12th Serbian Conference on Spectral Line Shapes in Astrophysics

Collisional contribution to the Spectral line shape in magnetized plasmas

The collisionnel contribution to the profil is also modified by the magnetic field

When the perturbers are electrons, the solution of the stochastic equation is usually achieved by using the impact theory of the interaction [M. Baranger].

In the standard model, the emitter supplied to successive independent collisions with electrons

The collective picture of the interactions with the electrons is generally described by a screened potential with Debye length

The solution of the stochastic equation is given in the impact regime : corresponding to a long time of interest greater than the mean collision time,

In the presence of magnetic field :

The collision operator must take in consideration the influence of $\vec{B}$ on the collision : in fact the perturbers trajectory is modified, and the velocities distribution too.

The trajectory of electron are helicoidal parrallel to $\vec{B}$, and Larmor radius

12th SCSLSA
3-7. June 2019
Vrdnik, Serbia

12th Serbian Conference on Spectral Line Shapes in Astrophysics

Collisional contribution to the Spectral line shape in magnetized plasmas

Define Larmor mean radius ρ_L corresponding to the most probable movement of the perturbers with thermal velocity v

$$\rho_L = \frac{m_e}{e\left|\vec{B}\right|} v \quad \longrightarrow \quad v = \sqrt{\frac{2kT}{m_e}}$$

In the impact theory, the Debye length ρ_D constitutes the upper limit on the impact parameters of the cross sections of the collisions

$$\rho_D = \sqrt{\frac{kT}{4\pi N_e q_e^2}}$$

If ρ_D is greater than ρ_L:

The influence of the trajectory curvature is not negligible in the presence of the magnetic field

12th SCSLSA
3-7. June 2019
Vrdnik, Serbia

12th Serbian Conference on Spectral Line Shapes in Astrophysics

Collisional contribution to the Spectral line shape in magnetized plasmas

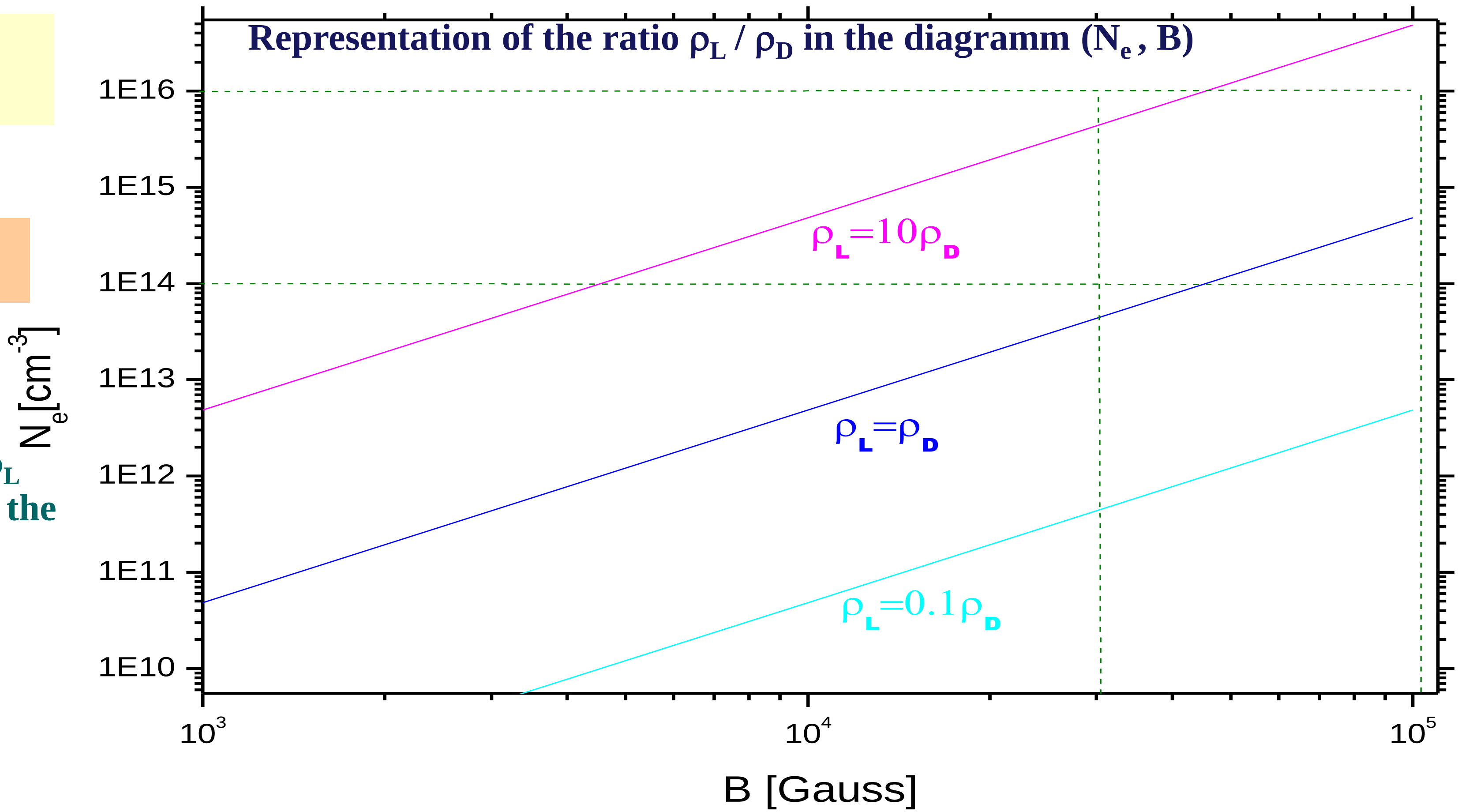
Debye Length :

$$\rho_D = \sqrt{\frac{kT}{4\pi N_e e^2}}$$

Larmor radius:

$$\rho_L = \frac{m_e c}{e\left|\vec{B}\right|} \mathrm{v}$$

The ratio ρ_D / ρ_L is independant of the temperature



In this figure, the lines show this ratio in the diagramm (N_e , B). This diagramm shows the non consideration of the trajectory effect is valid only *when the radius of Larmor ρ_L is greater than the length of Debye ρ_D (laboratory plasmas), for the rest of the cases, especially at low densities $N_e < 5.10^{14}$ cm-3 and for very strong fields B >10^5 G (astrophysical plasmas) the influence of the curvature of the trajectories is not negligible and then we have to take it into account.*

12th SCSLSA
3-7. June 2019
Vrdnik, Serbia

12th Serbian Conference on Spectral Line Shapes in Astrophysics

The collision operator in the presence of the magnetic field

The effects of electron collisions on the profil are treated in the impact approximation :

→ **a perturbative expansion (Dyson series) [H. Huddlestone et al] of the system emitter- perturbers**

→ **a multipolar developpment of the interaction allows to write**

$$\Phi = -\pi N_e \int \mathrm{v} f(\mathrm{v}) d\mathrm{v} \left[\rho_{\min}^2 + \frac{4}{3}\left(\frac{\hbar}{m}\right)^2 \frac{\vec{r}\cdot\vec{r}}{\mathrm{v}^2} \ln \frac{\rho_{\max}}{\rho_{\min}} \right]$$

$\vec{r}$ Is the position operator of the bounded electron

v Is the velocity of the perturbing electrons

$f(\mathrm{v})$ Is the distribution function of velocities

$\rho_{\max}\rho_{\min}$ **are the limits of the integral over impact parameter in the classical path approximation [Griem et al]**

Weisskopf radius [Griem et al] :

$$\rho_{\min} = \frac{n^2 \hbar}{Z m_e v}$$

n is the principal quantum number

Z is the nuclei charge

En présence du champ magnétique $\rho_{\max}$ vaut :

$$\rho_{\max} = \mathrm{v} \frac{1}{\sqrt{\left(\Delta\omega^2 + \Delta\omega_p^2 + \Delta\omega_s^2 + \Delta\omega_Z^2\right)}}$$

$$\rho_{max} = v \frac{1}{\sqrt{\left(\Delta\omega^2 + \Delta\omega_p^2 + \Delta\omega_s^2\right)}} + \frac{v}{\omega_L}$$

The collision operator in the presence of the magnetic field

$\Delta\omega$ Is the frequency separation in absence of any perturbation,

$\Delta\omega_p$ Is the electron plasma frequency

$\Delta\omega_s$ Is an estimation of the frequence shift due to linear Stark effect

$$\Delta\omega_s \approx 13\frac{n^2\hbar}{Zm}N_e^{\frac{2}{3}}$$

$\Delta\omega_Z$ Is the frequency separation of two extreme Zeeman components

$$\Delta\omega_Z = \frac{q_e}{cm_e\omega_0^4}\left|\vec{B}\right|$$

ω_0 Is the central frequency of the line

By using expressions of $\rho_{\max}$ and $\rho_{\min}$ the collision operator takes the following form :

$$\Phi \approx -\left(\frac{4\pi}{3}\right)\left(\frac{2m}{\pi k_B T}\right)^{\frac{1}{2}} N_e \left(\frac{\hbar}{m}\right)^2 \vec{r}\cdot\vec{r}\left(\frac{1}{2}\int_y^{\infty}\exp(-x)\frac{dx}{x}\right)$$

where $y \approx \left(\frac{\hbar n^2}{2Z}\right)^2 \frac{\Delta\omega^2 + \Delta\omega_p^2 + \Delta\omega_s^2 + \Delta\omega_Z^2}{E_H k_B T}$

Such that $E_H = \frac{q_e^2}{2a_0}$ is ionisation energy of hydrogen atom

The matrix elements of Φ are proportionnal :

$$\langle n\ell m|\vec{r}\cdot\vec{r}|n\ell' m'\rangle = \frac{9}{4}n^2\left[n^2 - \left(\ell^2 - \ell + 1\right)\right]\delta_{\ell\ell'}\delta_{mm'}$$

Such that $m = m_\ell$ because the operator in spin independent

The electron collision operator is then diagonal in the basis $\left(|n\ell s m_\ell m_s\rangle\right)$

12th SCSLSA
3-7. June 2019
Vrdnik, Serbia

12th Serbian Conference on Spectral Line Shapes in Astrophysics

Conclusion

In presence of the magnetic field:

- the non consideration of the trajectory effect is valid only when one is in the domain where the radius of Larmor ρ_L is greater than the length of Debye ρ_D *(laboratory plasmas)*, *for the rest of the cases, especially :low densities* $N_e < 5.10^{14}$ *cm-3 and for very strong fields* $B > 10^5$ *G (astrophysical plasmas) the influence of the curvature of the trajectories is not negligible and then we have to take it into account*.

- **The electron collision operator is diagonal in the basis** $\left(\left|n\ell s m_\ell m_s\right\rangle\right)$

- **The diagramm** $\left(N_e, |\vec{B}|\right)$ **presentes a description that allows us to precise the order of magnitude. Also it allows to precise the ranges of the validity of the various hypothesis. For example** the non consideration of the trajectory effect is appropriate for certains laboratory plasmas.

Références

[1] M. Baranger, « *Atomic and Molecular Processes* », Academic Press, New York, (1962).

[2] K. Touati, « *Analyse spectroscopique des plasmas en présence d'un champ magnétique* » Université de Provence Marseille (2003).

[3] H. Huddlestone, L. Stanley Leonard, « *Plasma Diagnostic Techniques* », Academic Press New York London, 1965.

[4] H. R. Griem, A. C. Kolb and K. Y. Shen, Phys. Rev. 116,4 (1956).

[5] H. R Griem et Blaha et P. C. Kepple, Phys. Rev. A 2421, (1979).